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A Progress Report To

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On Multidisciplinary Research On The  
Application Of Remote Sensing To  
Water Resources Problems

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**COLOR ILLUSTRATIONS REPRODUCED  
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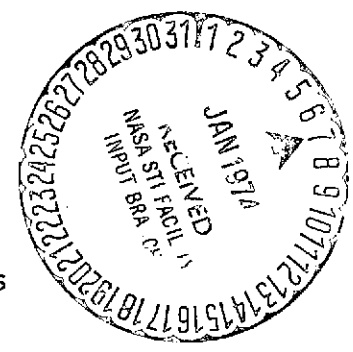
1972-1973

**ORIGINAL CONTAINS  
COLOR ILLUSTRATIONS**

from

James L. Clapp, Project Leader

Institute for Environmental Studies  
The University of Wisconsin  
Madison, Wisconsin 53706



(NASA-CR-136280) ON MULTIDISCIPLINARY  
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## I. INTRODUCTION

This is a progress report on NASA's grant to the University of Wisconsin for Multidisciplinary Research on the Application of Remote Sensing to Water Resources Problems. During the 1972-73 period efforts were made to sharpen the focus of this research program to applied rather than basic research.

The fundamental objectives of the research conducted during the 1972-73 period were:

(1) To ascertain the extent to which special aerial photography can be operationally used in monitoring water pollution parameters through a comparison of photo imagery and pollution parameters.

(2) To ascertain the effectiveness of remote sensing in the investigation of nearshore mixing and coastal entrapment in large water bodies. During the course of the past year this project has been focused upon the delineation and definition of thermal plumes discharged into the Great Lakes from power-generating stations.

(3) To develop an explicit relationship of the extent of the mixing zone in terms of the outfall, effluent and water body characteristics, and to apply aerial remote sensing methods to the definition of the boundaries and concentrations of waste effluents in the mixing zone.

(4) To develop and demonstrate the use of the remote sensing method as an effective legal implement through which administrative agencies and courts can not only investigate possible pollution sources but also legally prove the source of water pollution.

(5) To evaluate the field potential of remote sensing techniques in monitoring algal blooms and aquatic macrophytes, and the use of these as indicators of lake eutrophication level.

(6) To develop a remote sensing technique for the determination of the location and extent of hydrologically active source areas in a watershed.

The remote sensing program is related to and works with many other research programs of the University of Wisconsin-Madison, and state and federal agencies. Included in these are International Biological Program, Marine Studies Program of the U/W Marine Studies Center, State of Wisconsin Department of Natural Resources, and the U.S. Attorney's Office. Because of the interaction between the remote sensing program and these other related projects and agencies the program is administered by the Institute for Environmental Studies in the Environmental Monitoring and Data Acquisition Group,

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which is specifically designed to accommodate this type of interdisciplinary work.

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## II. APPLICATION OF REMOTE SENSING TO THE DETERMINATION OF WATER QUALITY

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### ABSTRACT

Since its beginning this research has been directed toward development of a practical, operational remote sensing water quality monitoring system that can be used by individuals, private firms, and governmental agencies. To accomplish this it was first necessary to develop the camera, ground truth, and photo analysis hardware and a proper technique for indexing, filing, and retrieving the remote sensing data. It was also necessary to establish what water quality parameter correlates with the aerial photos being analyzed. Noise factors such as bottom effects and skylight reflection must also be understood and properly dealt with.

When these three categories of factors are properly understood and are operationally taken care of, then remote sensing is ready to be used as an operational tool for water quality monitoring.

Through the efforts of more than a dozen staff and graduate students over the last six years, the cameras and other hardware are now completely operational and reliable. Through the recently completed Ph.D. program of Dr. Ramchandra Singh an indexing, filing, and retrieval system for remote sensing data is now operational.

It has been established that the water quality parameter of turbidity reliably correlates at all times with the reflection captured on the aerial image. On any one day other parameters such as solids and colors may also correlate with turbidity but this correlation changes with time.

Bottom effects are now completely understood and can be handled by use of a secchi disc and curves developed over the past five years. A procedure for handling the skylite reflection is now theorized and is being worked out as a Ph.D. project by John Van Domelen. Present knowledge allows one to map the turbidity and solids of a water body if a few simultaneous water samples are taken to establish the amount of skylite reflection. The results of John Van Domelen's work by June 1974 will show if there are better methods of handling the skylite reflection problem with fewer simultaneous water samples.

By June 1974 all the facts will be known so recommendations can be made for the optimum system of monitoring water quality by remote sensing. In preparation for this operational use within the state agencies, a graduate student, Robert Clegg, has been designated to work with the Wisconsin State Department of Transportation (DOT) to assess the potential use of photos already taken by our 35mm camera system for monitoring environmental impact in their highway operations. Present work by Professor James Clapp and the administration section of this project involves correlating with the State Department of Natural Resources (DNR) on the potential use of remote sensing in their water quality work. If results of this coordination are positive, the full knowledge which will be available in June 1974 can then be put into operation by the State DOT airplanes and our cameras. The DOT will already have gained experience in the use of the hardware in their operational monitoring and can begin gathering data for the DNR's water quality monitoring programs as desired.

#### A. Present Status of Investigation

##### 1. Hardware and Data Retrieval

Various cameras have been used by the project, but the most usable, versatile and economical system is the bulk 35mm camera bank (4,5). A spectrophotometer apparatus has

been fully developed for reliably obtaining reflectance and transmittance of water samples (2, 12, 13). A microdensitometer attached to this spectrophotometer allows one to completely analyze a photo for intensities at any color (1, 2, 12, 13).

The 35mm bulk film is easily handled by microfilm techniques; a very workable system has been developed for indexing it as well as other remote sensing data (6, 14, 15). The hardware and data filing and retrieval system are all fully developed and are fully in operational use.

## 2. Correlation of Water Parameter with the Aerial Image

For heavy paper mill waste, inorganic clay runoff, and clear-water lakes it has been shown that it is the parameter of turbidity that correlates at all times with the reflectance captured by the aerial photo (2, 12, 13). Figure 1 shows the reflectance-turbidity curve for water which is heavy in inorganic clay runoff collected from Lake Superior on three different days. The dirty water caused by a heavy storm remained in the area for three weeks but its character did change due to settling of heavy particles. One turbidity-reflectance curve held for all three days. Figure 2 shows the area where these samples were taken.

Figure 3 shows that there is good correlation between turbidity and secchi disc readings for all days. This is logical because the secchi disc is really just a field means of obtaining turbidity. Figure 3 also shows that the correlation between suspended solids and turbidity is good for any one day but that this correlation changes from day to day.

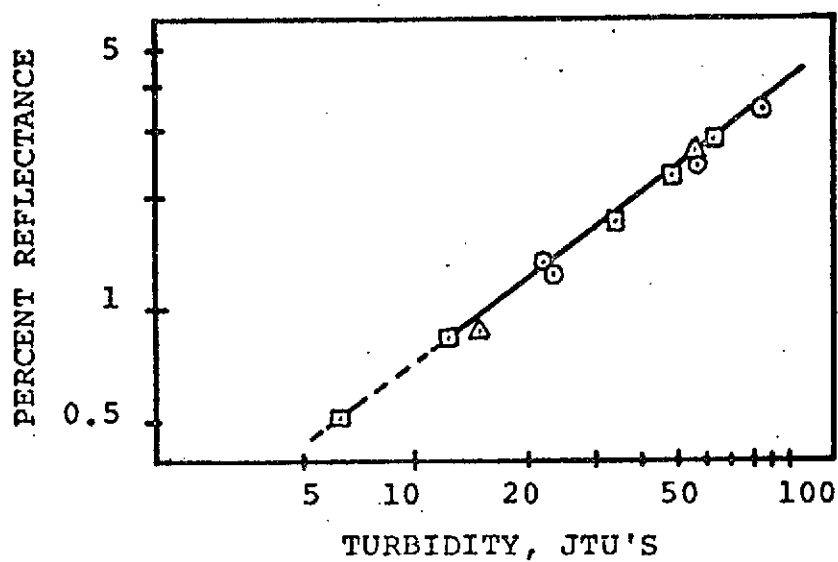
For the situation shown in Figures 1, 2 and 3, only the parameters of suspended solids and color come close to correlating with turbidity. Other work has shown that at times Fe correlates to turbidity because the solids can be largely Fe.

Because turbidity always correlates to reflectance seen on the photo, turbidity on a photo such as Figure 2 can be mapped from proper analysis of the photo. On any one day other parameters such as solids may also correlate to turbidity and can be so mapped. To do so, a few simultaneous water samples must be taken to establish the relationship between turbidity and solids.

## 3. Noise Factors

Depth penetration and bottom effects are very important because visible light may penetrate through the water and





### Reflectance vs. Turbidity

- ⊙ = Water Samples Collected 4 November 1972  
(2 days after a heavy storm)
- △ = Water Samples Collected 17 November 1972
- ▣ = Water Samples Collected 23 November 1972

Figure 1: Reflectance-turbidity curve for dirty water collected on three different days from Lake Superior.



Figure 2. ERTS Satellite Image taken 12 August 1972 showing the southwest end of Lake Superior near Duluth. Note the dirty water. An X marks the spot where an \$8,000,000 water intake was located which when put into operation produced turbid unusable water.

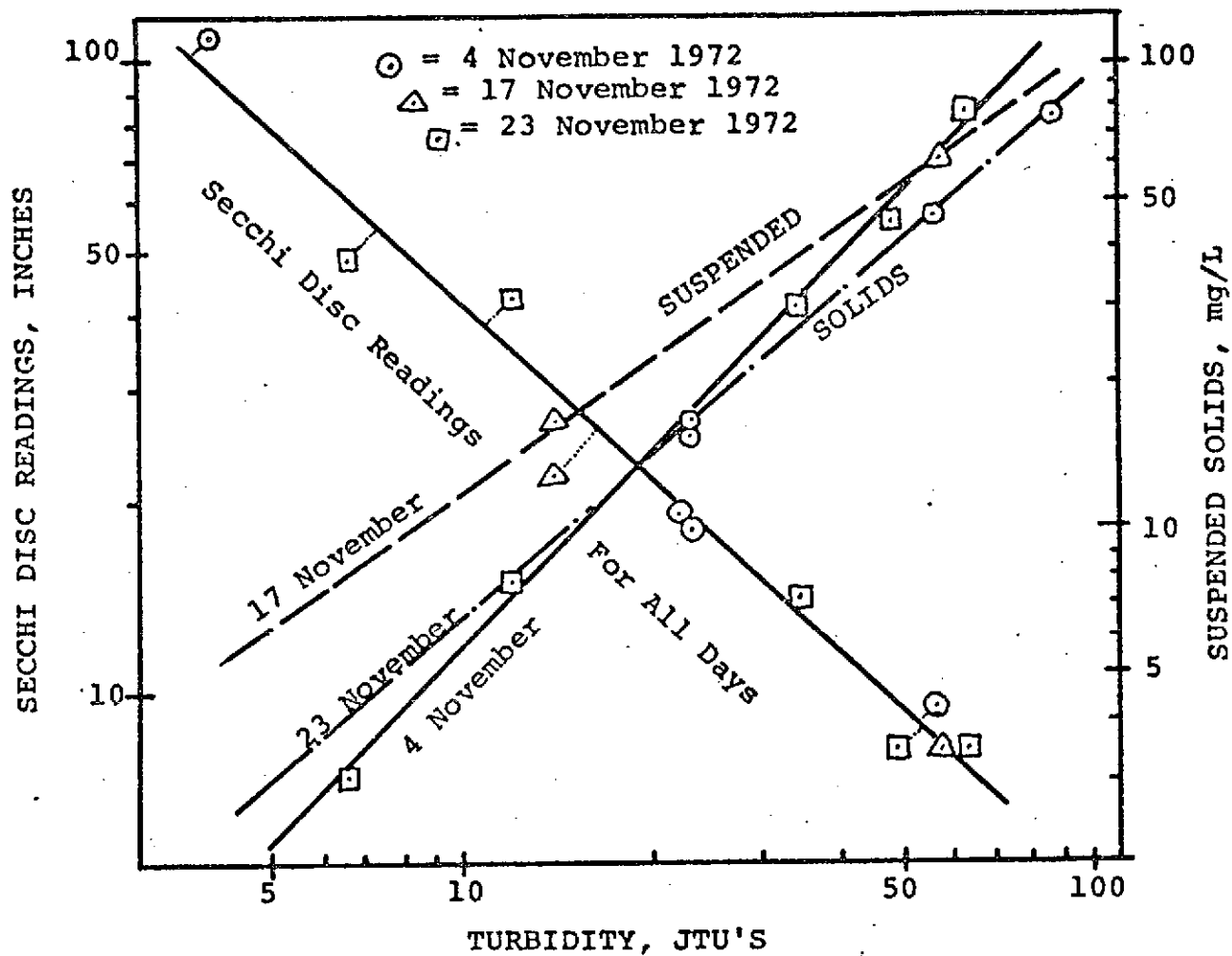


Figure 3. Plot of secchi disc readings and suspended solids versus turbidity for all of the water samples collected in dirty water in Lake Superior near Duluth in November 1972.

show the bottom. Polluted water underlying clear surface water may also show on an aerial image (10). The water must be properly sampled at depth to make proper correlation of water sample to aerial image.

The secchi disc is a good means of establishing bottom effect phenomena. Only about 1% of the total upwelling light originates from below the secchi disc readings (10, 11).

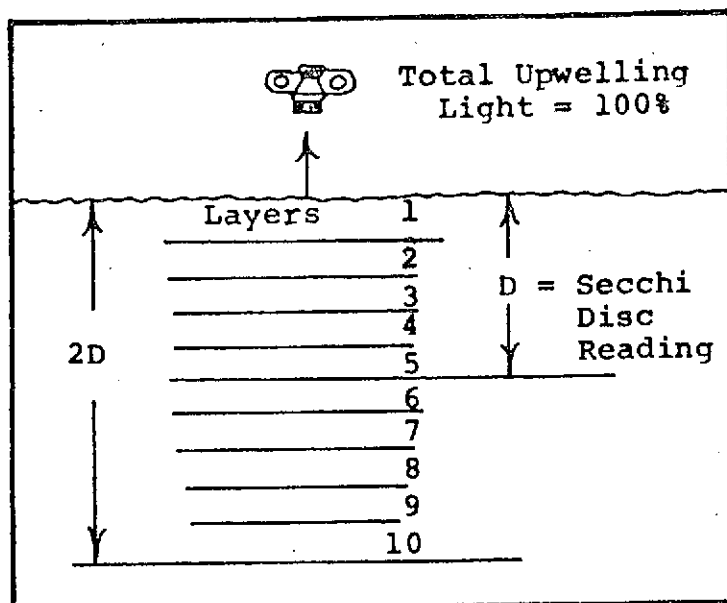
Figure 4 shows a plot of the percent of upwelling light that comes from each of five layers created above the secchi disc reading. The curve also shows what percentage of a total composite water sample must be taken from each of these layers for proper correlation of the water samples to the aerial image (10, 11).

As a general rule, if the secchi disc reading is less than the depth to bottom, bottom effects are not significant. If the secchi disc reading is greater than the depth to bottom, then bottom effects are significant and for analysis in these waters the photographic infrared energy must be used because it penetrates only a few inches into the water (3, 7).

Since there is a relationship between the reflectance of a water and its secchi disc readings, it is possible to obtain the depth of penetration into water from analyzing an aerial photo (12). Figure 5 shows a plot of the lab reflectance of water samples taken from Lake Superior versus the secchi disc reading. By obtaining the reflectance from a photo such as in Figure 2 one can, from Figure 5, determine how far one is seeing into the water. In this case the secchi disc reading and the maximum depth of penetration of light is less than 10 feet. The depth to bottom in this area of Lake Superior is from 50 to 70 feet. Therefore without doubt one is not seeing the bottom in Figure 2.

The apparent reflectance of water in the field obtained by taking a spectrophotometer into the field or by analyzing aerial photos is always greater than the reflectance of the same water obtained in the laboratory. This is true because in the field the skylight is also reflecting from the water surface.

Figure 6 shows field and lab reflectance-turbidity curves for papermill waste taken on 28 August 1972. Figure 7 shows field and lab curves for the inorganic water shown in Figure 2 for photos taken on 4 November 1972. Figure 8 shows field and lab curves for clear-water lakes near Ely, Minnesota for water samples collected on 10 July 1973. In all cases the reflectance-turbidity curves from the photos are higher than the curves from the lab because the aerial photos contain



SKETCH OF MODEL

Percent of upwelling light that comes from each layer at depth. Also the percent of composite water sample that should be collected at different depths.

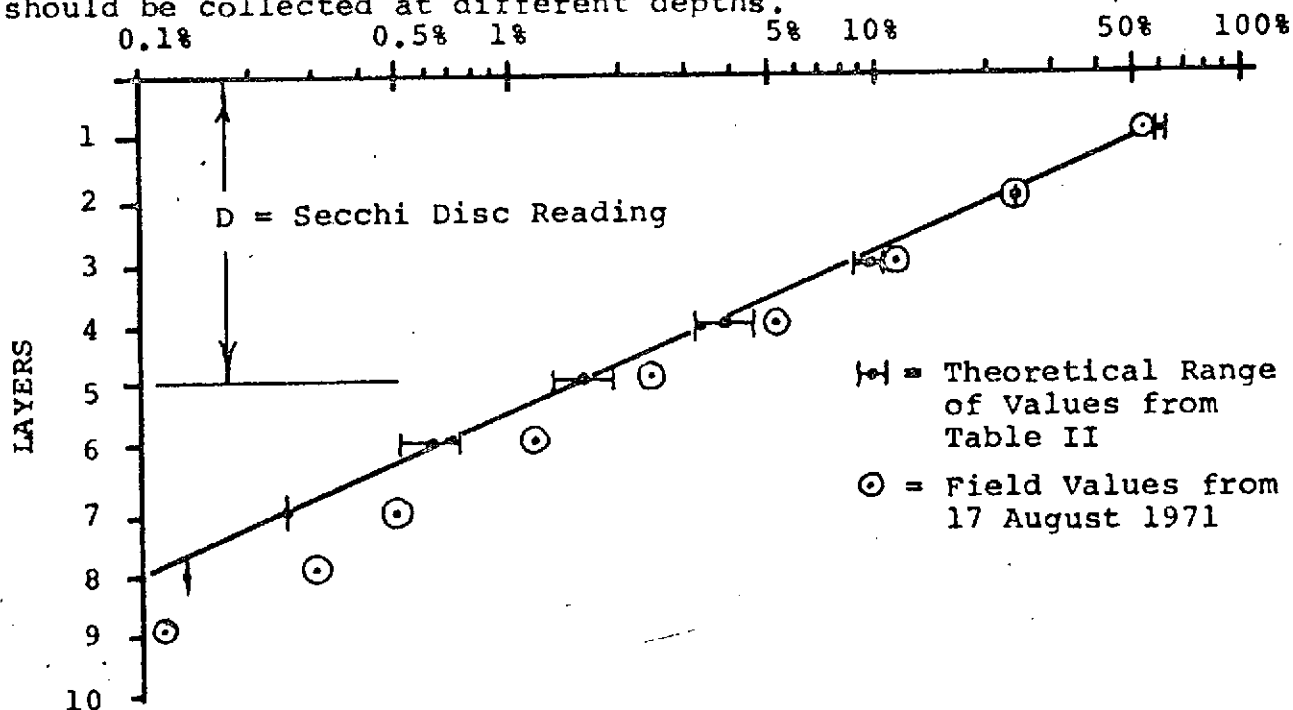
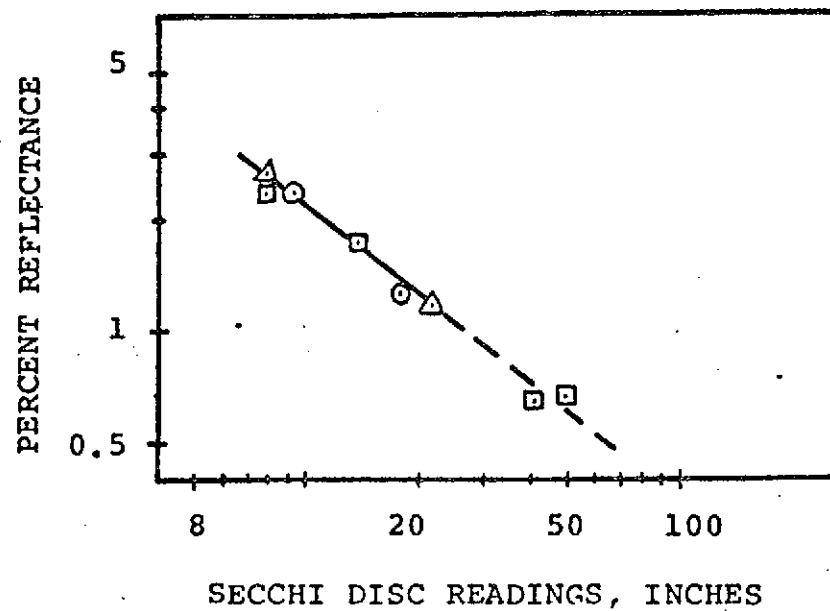


Figure 4. Curve showing percent of total upwelling energy that comes to the camera from each layer in the water. The curve can also be used to show how a composite depth sample should be taken for remote sensing correlation.



Reflectance vs. Secchi Disc Readings

Figure 5. Laboratory reflectance versus turbidity and secchi disc readings for all of the water samples collected during the three days in November 1972. The location is dirty water in Lake Superior near Duluth as shown in Figure 8.

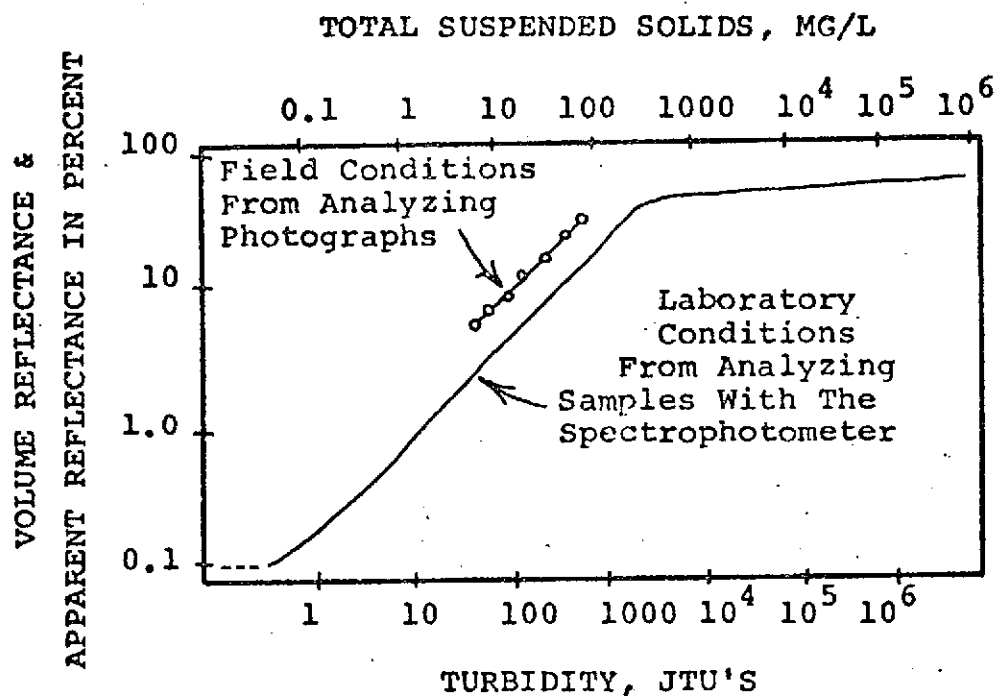


Figure 6. Volume reflectance for laboratory samples and apparent reflectance for field conditions plotted against turbidity and total suspended solids. The wavelength used was 0.55 micron (color green). The fact that the apparent reflectance from field conditions is higher than the lab conditions is primarily due to skylight reflection. The aerial photos show skylight reflection, while the lab analysis does not.

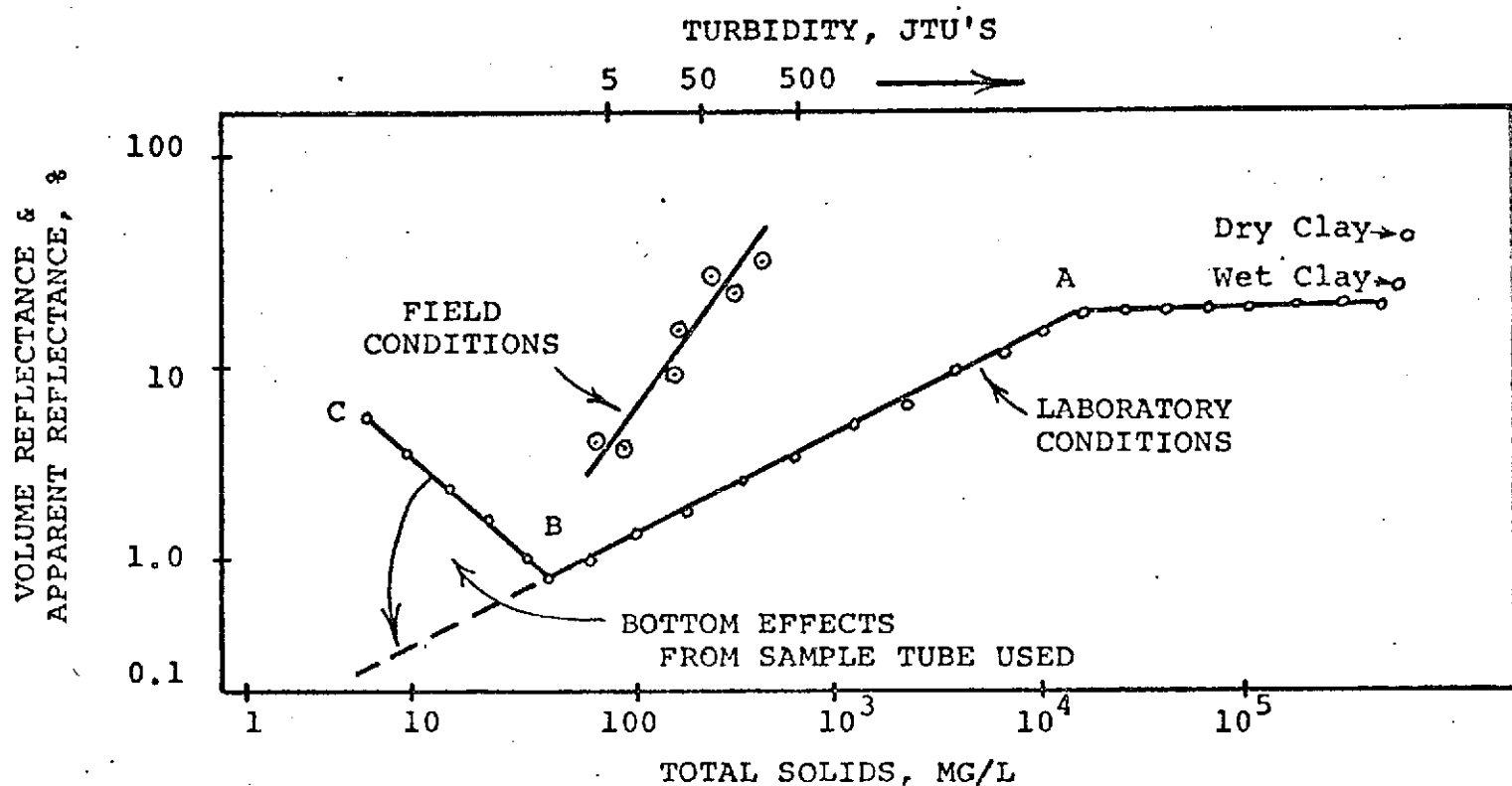


Figure 7. Laboratory volume reflectance and also apparent reflectance from color and color infrared photographs plotted against turbidity and total solids. The wavelength used was 0.65 microns (color red). The location is Lake Superior near Duluth. The material in the water is red clay which shows up on aerial photos and ERTS images. On the laboratory analysis between points B and C the effects of a shiny bottom of the sample tube are overriding, making this data erroneous. These effects have subsequently been reduced by using a flat black bottom for the tube. The vertical displacement between the curve for field conditions and lab conditions is primarily due to the fact that skylight reflection is present on the photos, but not present in the lab analysis.



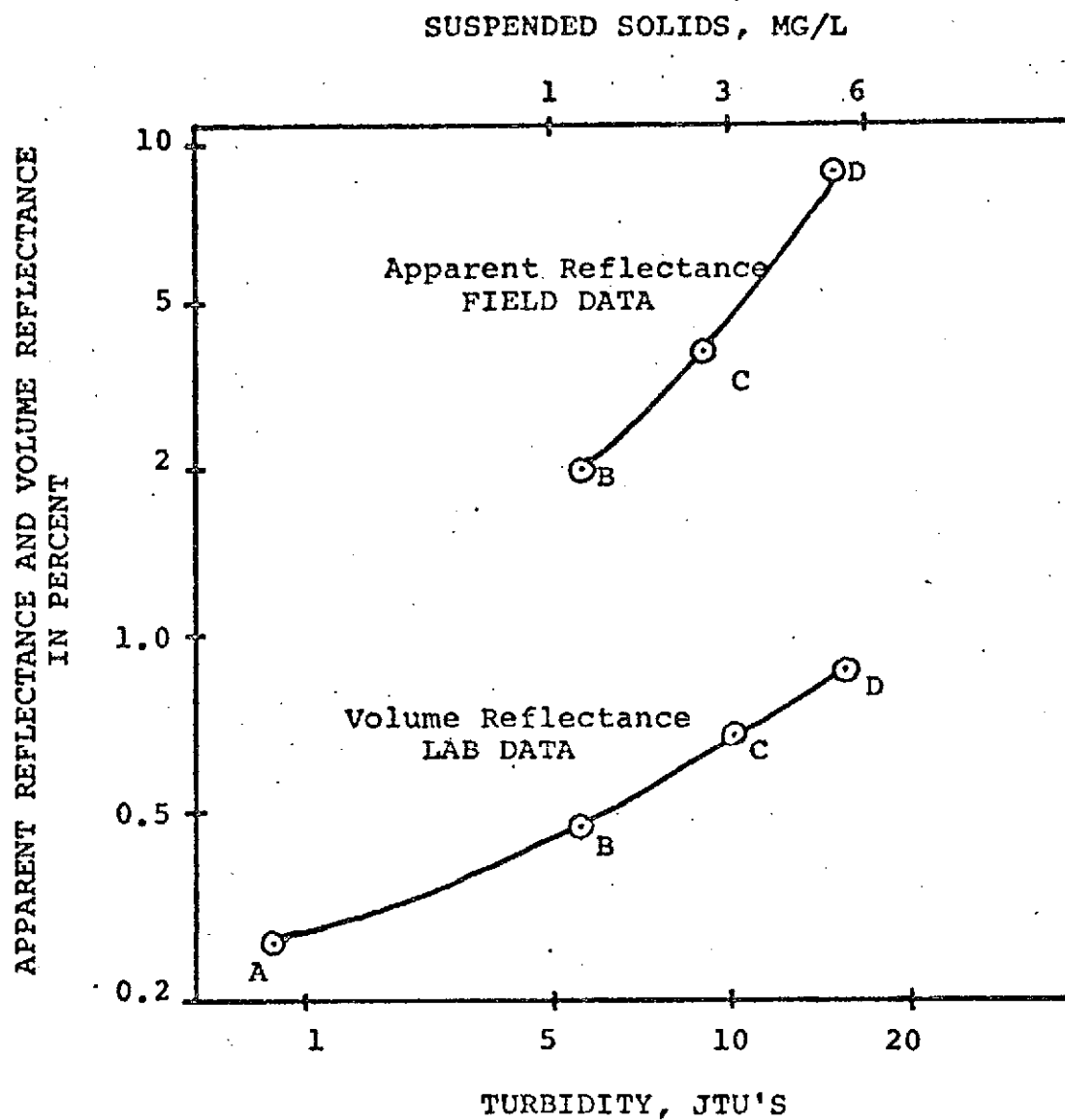


Figure 8. Volume reflectance from analyzing water samples in the lab and apparent reflectance from ERTS imagery plotted against turbidity and suspended solids. The three lakes analyzed are classified in three different stages of enrichment or eutrophication as follows:

<u>Sample</u>	<u>Lake</u>	<u>U.S. Forest Service Classification</u>
A	Distilled water	NA
B	Snowbank Lake	Oligotrophic (clear)
C	Ensign Lake	Mesotrophic (middle stage)
D	Shagawa Lake	Eutrophic (enriched)

skylight reflection. A few water samples must be taken simultaneously with the aerial photos to ascertain the exact skylight reflection effect.

This skylight effect can change drastically from day to day and for different altitudes. Figure 9 shows results of analyzing aerial photos of papermills in Wisconsin in 1971. The results of this analysis clearly point out that for any one day and set of atmospheric conditions, there is indeed a good curve between reflectance and turbidity but that the skylight condition as well as the altitude drastically affect these curves.

To ascertain the exact skylight and atmospheric effect for a set of photos, it appears that a few simultaneous water samples must be taken to ascertain the exact location of the reflectance-turbidity curve. Once this is done, turbidity anywhere in the set of photos can be mapped from proper photo analysis. The effects of skylight reflection are being thoroughly investigated by John Van Domelen. His results should be complete by June 1974.

#### B. Future Work

Be it for a court case, planning or water quality monitoring, the bottom and skylight effects must be thoroughly understood and properly handled. Once this is done it is possible to obtain quantitative values of turbidity and sometimes suspended solids from analyzing the aerial or satellite images. By June 1974, the final recommendations for handling skylight reflection will be complete and remote sensing for water quality monitoring should be fully ready for implementation for private use or for use by governmental agencies.

The administration and management section of this project under Professor Clapp has taken the responsibility of establishing relationships with the Wisconsin Department of Natural Resources which would logically use remote sensing for its water quality monitoring. Such a system should be ready for use by the state by June 1974.

In the meantime, a graduate student—Robert Clegg—has been assigned to begin work with the State Department of Transportation to test the camera and data retrieval system for their work. By June 1974 this department with its aircraft and our cameras will be ready to begin taking appropriate aerial pictures for any desired water quality monitoring work.

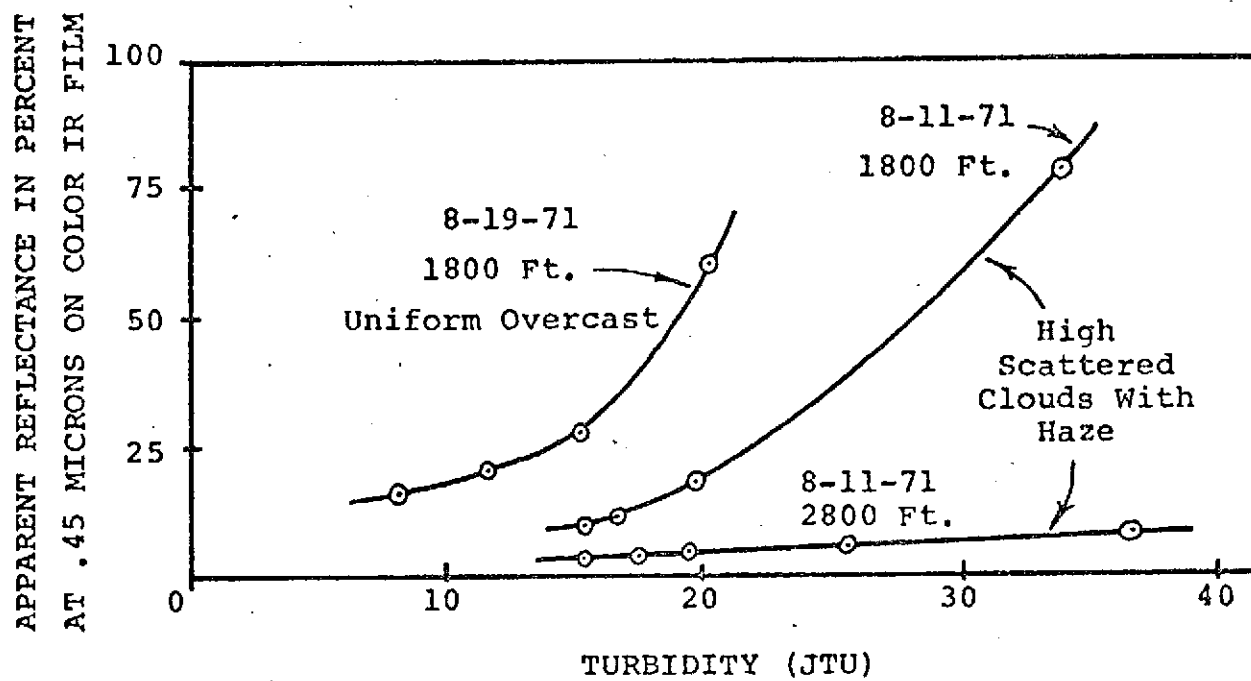


Figure 9. Change in reflectance-turbidity curve due to changes in cloud conditions and altitude.

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### III. APPLICATION OF REMOTE SENSING TO THE INVESTIGATION OF NEARSHORE MIXING AND COASTAL ENTRAPMENT IN LARGE WATER BODIES

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Engineering

Robert A. Ragotzkie, Professor, Department of Meteorology,  
and Director, Marine Studies Center

#### ABSTRACT

In the 1972-73 proposal, this project was directed towards a broad based analysis of nearshore mixing and coastal entrapment in the Great Lakes. During the course of the past year, with consultation with NASA officials, the effort was sharply focused upon the current problem of thermal discharge into the lakes from power plants.

#### BACKGROUND

Over the past few years, great controversy has centered on the use of Great Lakes water to cool large power plant condensers. The water is abundant and the cooling process relatively cheap. In the process, the water is heated about 10°C and then put back into the lake, forming a warm water region, or "thermal plume."

Thermal plumes can have harmful effects on life in the lake. Whether or not these effects are sufficiently harmful to be a legitimate cause for concern is unclear. All of the facts are certainly not yet in, especially on the more subtle, long-term consequences. Nonetheless, costly decisions are now being made on the suspicion of environmental damage. Cooling towers, with their own attendant environmental effects, are now under construction. In view of the well documented rate of increase of power generation, the situation deserves careful study. Once the effects of thermal plumes are reasonably well known, the public can, hopefully, put a price tag on this cooling method in an environmental cost-benefit analysis.

## THERMAL PLUMES

Thermal plumes are not easily studied. The plume itself is the cause of most of the biological, chemical and geological effects of power plants, and must be understood if we are to clearly appraise these effects. The plume must be viewed as a partly random response to environmental factors such as wind, waves, local turbulence, and nearshore lake currents. Because of limitations in predicting these factors, any prediction of plume behavior should be accompanied by error bounds. But, because of our ignorance of plume variability, such bounds are usually lacking. The same limitations are even more true in looking at the effects of thermal plumes. Measuring numbers and types of fish is much more difficult than measuring water temperature. Sampling problems and random fluctuations make the results of short-term studies suspect.

To assess the real dangers of thermal plumes, a large body of data, acceptable to all parties, is needed. When this exists, it may well be that many feared effects are smaller than those due to natural fluctuations of lake temperature.

## UNIVERSITY OF WISCONSIN THERMAL PLUME RESEARCH

The University of Wisconsin-Madison has been studying thermal plumes on Lake Michigan for four years. The Point Beach Nuclear Plant at Two Creeks, Wisconsin, is convenient for study, and has been emphasized. The money has come from the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration Sea Grant Program, the National Science Foundation, the Office of Water Resources Research, and various power companies.

The research is being done by a coordinated team: fluid dynamicists are trying to understand the plume itself; biologists are using sophisticated tracking techniques to ascertain the behavior of fish in the plume; and geologists are determining the shore erosion patterns near this new "river" entering the lake.

We find that the Point Beach plume is quite complex. The upwind edge often meanders noticeably and sharp thermal fronts sometimes spread outwards from the outfall. Temperature gradients are much larger than those predicted by mathematical models. Biological studies reveal that fish often alter their course radically upon encountering the plume during longshore migration.

Beach profiling studies show that local shore erosion is unrelated to the power plant. Detailed information on these and other effects is available from our program on request.

This comprehensive research effort has more than one goal. In the short-term, data are used for power-plant siting decisions. Also, the data gathered before February, 1974 on thermal plumes on Lake Michigan will then be used by Wisconsin DNR to set temperature standards for these plumes. However, the same data are also contributing to our basic understanding of phenomena such as fish behavior in temperature gradients and turbulence in stratified shear flows. Because such fundamental studies demand extremely high quality data, measurement accuracy and sampling techniques receive careful attention. This also benefits the more immediate user of the data.

### THERMAL SCANNING

The university is playing a role in providing unbiased, basic data for public decision making. The thermal scanning program, now being conducted jointly by UW-Madison (with support from NASA and NSF), the Wisconsin Department of Natural Resources (Wisconsin's environmental enforcement agency), and the three major Wisconsin power companies (the affected industry) is one example. As mentioned above, these data will be used early next year to set water quality standards.

Our experience has shown that temperatures measured simultaneously at many points are very important for an accurate plume description. Airborne thermal scanning does just that, for plume surface temperatures. Since the warmest water is usually at the lake surface, such data are ideal for use with the water-temperature standards couched in terms of mixing zones.

The success of the scanning program is derived, in large part, from the day-to-day cooperation among the three groups involved. The pilots and aircraft, a DC-3 specially equipped with a high-accuracy navigation system, are supplied by the Wisconsin DNR. The relatively large size of the aircraft helps eliminate unknown image distortions caused by flight-speed and pitch variations, due in turn to atmospheric turbulence. The power companies take ground-truth temperature measurements and have also provided a new thermal scanner and money for aircraft maintenance. The university group actually does the scanning and analyzes the data. Consulting groups, working directly for the power companies, have been collecting supporting data while this research is being conducted.



Thermal scans of the seven major thermal plumes on the Wisconsin shore of Lake Michigan are made about twice weekly. So far, over 500 scans have been made and 300 more will be taken by the end of the program (see Table 1 and Figure 1). Plans are now being made to extend the scanning program to include the entire coastal zone of Lake Michigan. This would be a simple extension of our ongoing work, and would probably be the most cost-effective method of monitoring man's total heat input to the lake.

The scanning program is yielding a vast amount of data. Although it will be some time before these data are completely analyzed, we nevertheless can make general statements now which are very important to ascertaining both appropriate water quality standards and strategies for measuring plumes. Such statements should only be made about "clean" plumes, free from the complexities introduced by complicated outfall design or shore configurations. This limits the available data to that from Point Beach (before the second outfall went into operation), Edgewater, and Port Washington.

In general, these plumes can be put into four categories. "Smooth" plumes (Figure 2) behave as we might expect plumes to behave: surface temperature gradients are small and vary gradually over the plume. "Rough-water" plumes (Figure 3) hug the shore and are puffy and discontinuous. They occur in conjunction with high winds and waves. "Front-laden" plumes (Figure 4) are dominated by a series of concentric sharp temperature gradients, or fronts, which spread radially outward from the outfall. They occur primarily on very calm days. Finally, "meandering" plumes (Figure 5) exhibit a meandering instability of the upwind edge. The latter two categories occur quite often and seem to account for over half of the total. Some plumes (Figure 6) fall into none of these categories and are probably associated with a wind change.

Much more definite statements can be made once the data are completely analyzed. This, however, will not happen soon. The project is still in the data-collection phase. Of course, the data available will all be used shortly to set thermal standards for the plumes under study.

TABLE 1. THERMAL SCANNING FLIGHTS  
 Wisconsin Shore of Lake Michigan

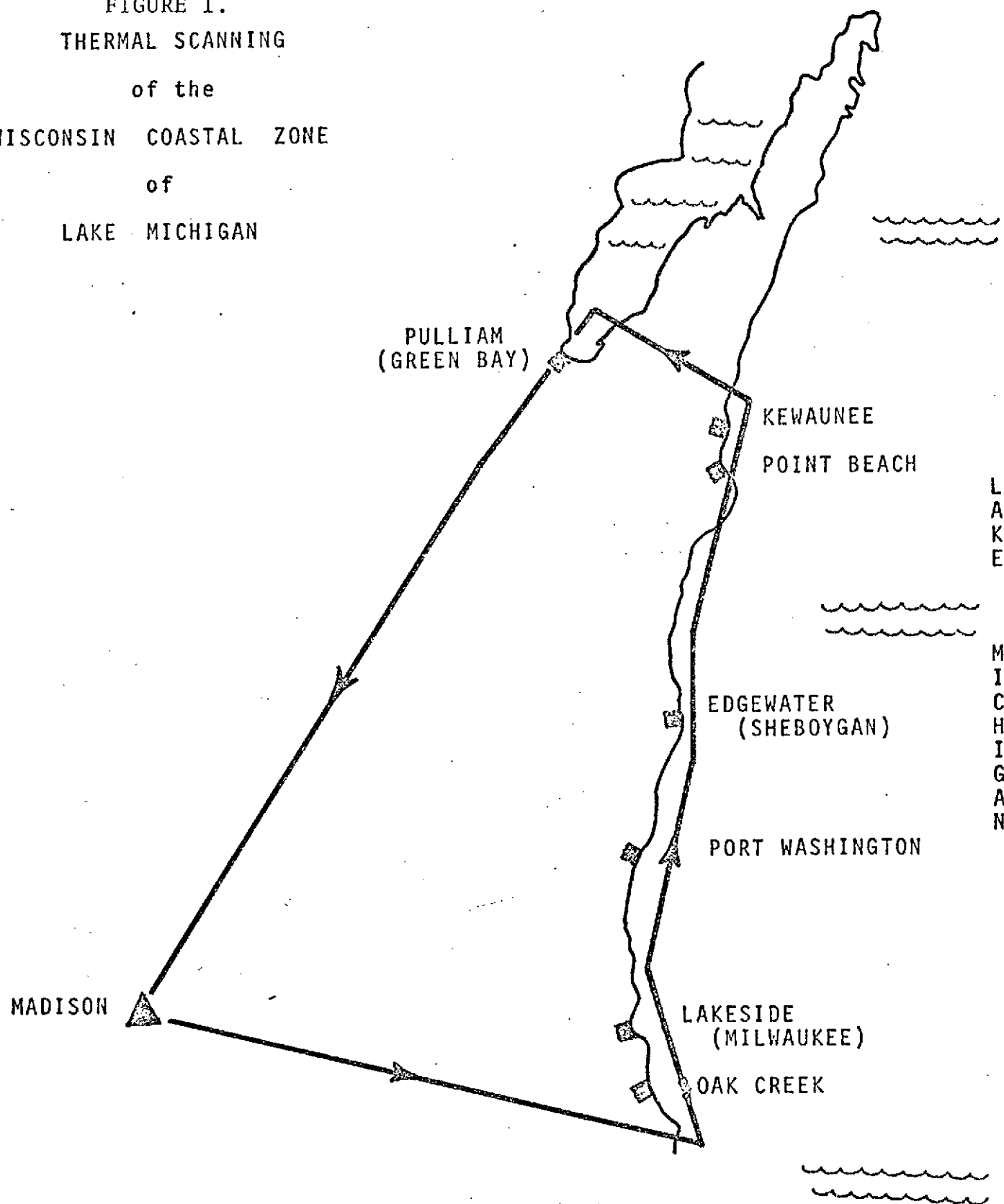
Date	Routine Flight*	Other	Remarks
1/30/73	x	Deer Survey	
2/5/73	x		
2/9/73	x		
2/12/73	x	Deer Survey	
2/15/73		Deer Survey	
3/20/73	x	Ground Water Survey Door County	Cooperation with USGS
3/23/73	x		
3/27/73	x		
3/28/73	x		
4/5/73	x		
4/11/73	x		
4/12/73	x		
4/17/73	x		
5/11/73	x		
5/17/73		Extensive Flight Point Beach	
5/18/73		Extensive Flight Point Beach	
5/24/73	x		
5/30/73	x		
5/31/73	x		
6/6/73	x	Door County	USGS—Coordination with Argonne
6/7/73	x		Coordination with Argonne

continued next page

Date	Routine Flight*	Other	Remarks
6/14/73	x		
6/15/73	x		
6/18/73		Oak Creek, Lakeside Port Washington	Fog North Port Washington
6/25/73	x		
6/26/73	x	Except Green Bay	Storm
6/27/73		Point Beach Kewaunee	Inclement weather
7/3/73	x		
7/10/73	x		
7/10/73	x		
7/11/73	x		
7/17/73	x	Except Point Beach, Kewaunee, Green Bay	Inclement weather
7/18/73	x	Except Green Bay	Inclement weather
7/26/73	x		
7/27/73	x	Includes Zion, Ill.	
8/10/73		Extensive flight at Point Beach	
8/12/73	x		
8/13/73	x		
8/14/73	x		
8/15/73	x		
8/16/73	x		
8/17/73	x		
8/20/73	x		

\* Normally includes Oak Creek, Lakeside, Port Washington, Edgewater (Sheboygan), Point Beach, Kewaunee, and Pulliam (Green Bay) Power Plants.

FIGURE 1.  
THERMAL SCANNING  
of the  
WISCONSIN COASTAL ZONE  
of  
LAKE MICHIGAN





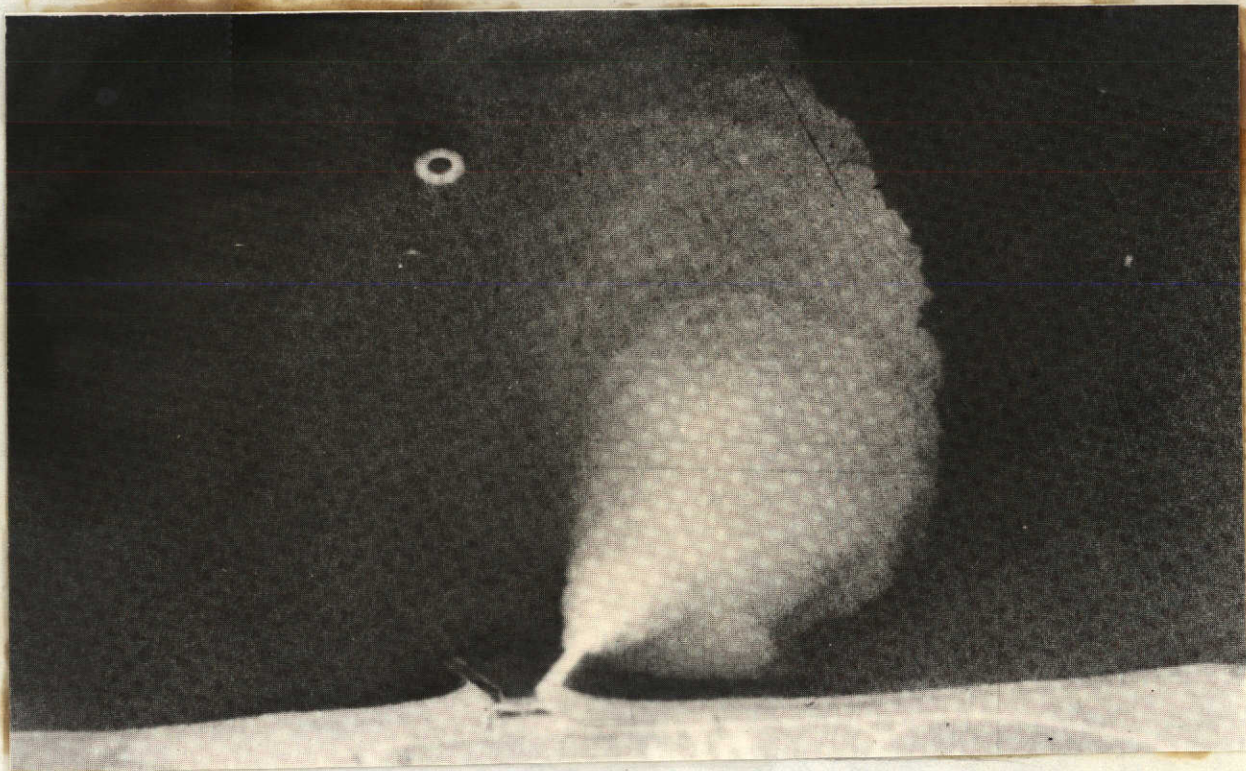


Figure 2. A "smooth" plume.

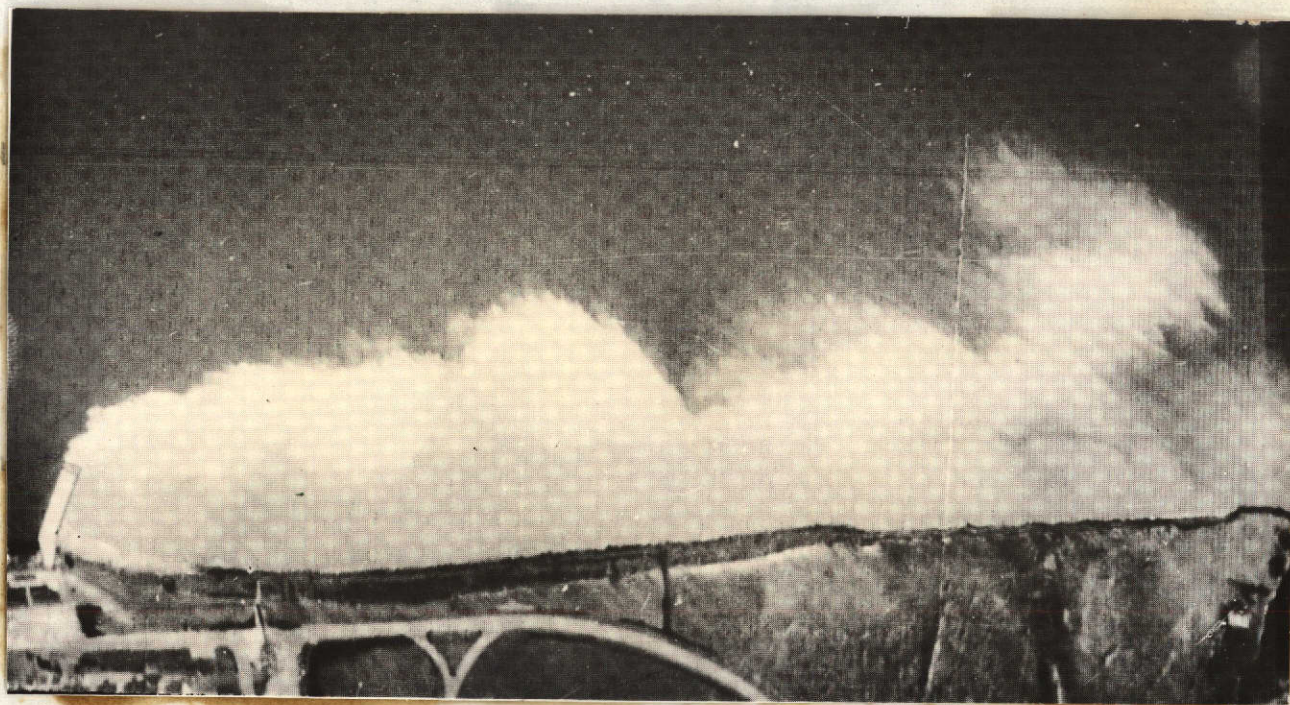


Figure 3. "Rough-water" plume hugs the shore, is puffy and discontinuous.



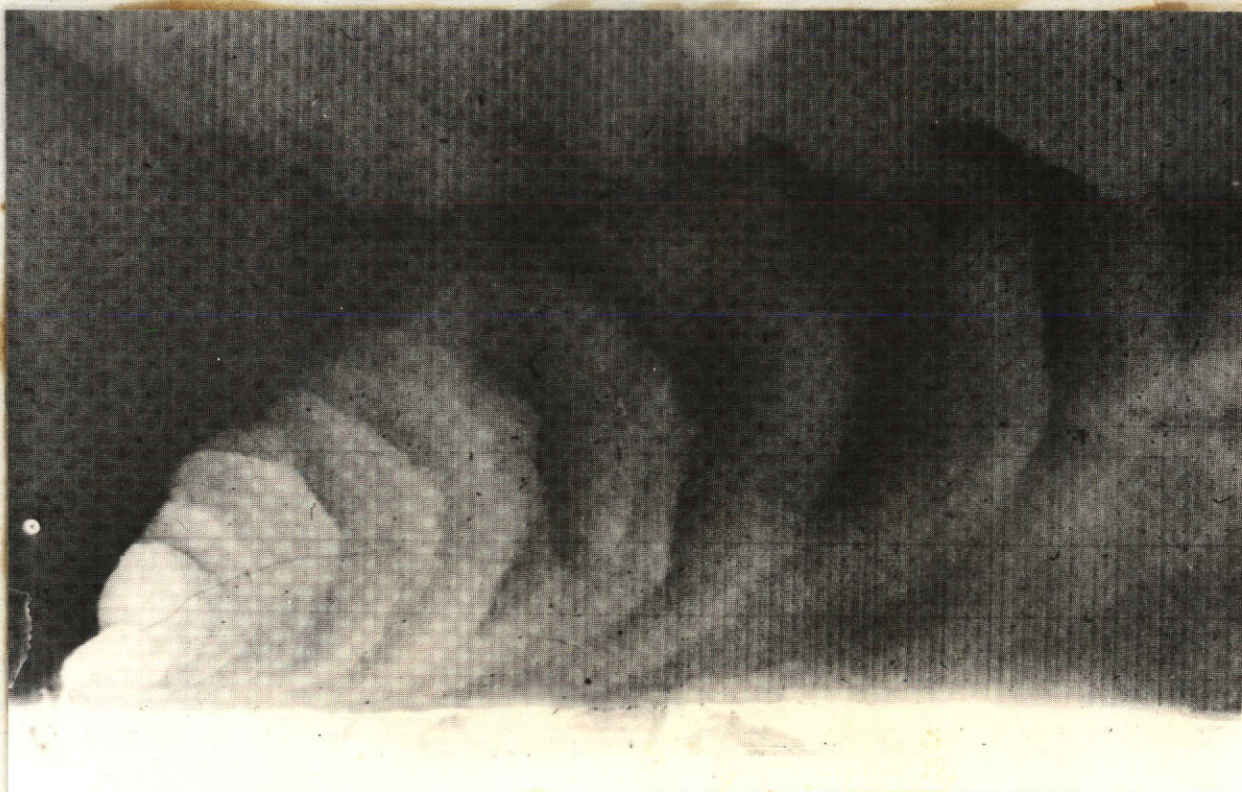


Figure 4. "Front-laden" plume, dominated by a series of concentric sharp temperature gradients or fronts.



Figure 5. "Meandering" plume exhibiting a meandering instability of the upwind edge.



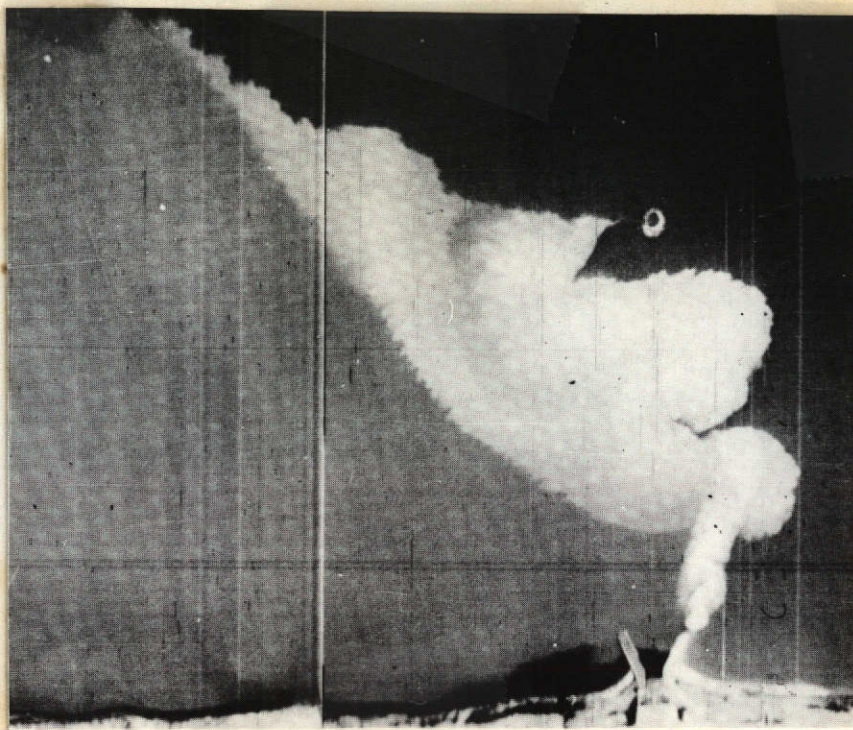


Figure 6. A plume falling into none of the other categories, probably associated with a wind change.

IV. APPLICATION OF REMOTE SENSING TO THE  
DETERMINATION OF MIXING ZONES FOR EFFLUENTS  
DISCHARGED INTO STREAMS OR RIVERS

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ABSTRACT

Basic goals of this project are: 1) to develop an explicit relationship on the extent of the mixing zone in terms of the outfall, effluent and water body characteristics, and 2) to apply aerial remote sensing methods to the definition of the boundaries and concentrations of waste effluents in the mixing zone. Such a relationship will be useful to governmental agencies in the establishment of water quality guidelines and monitoring programs and to industries and municipalities in the design of outfalls.

Through an extensive literature search, a working hypothesis for the extent of the mixing zone as a function of outfall, effluent and water body characteristics has been formulated. Laboratory models have been tested to study the effects of outfall, effluent and river characteristics on the rate of effluent mixing and spreading and to study modeling requirements and results for a particular site. Mathematical models of effluent discharges into stationary and moving environments including boundaries have been analyzed to determine the rate of effluent mixing as a function of distance from the outfall. Field measurements of effluent discharge mixing at seven sites throughout the State have been undertaken to study the effects of effluent, outfall and water body characteristics on the rates of effluent mixing and spreading. During the past year, intensive



aerial remote sensing (photogrammetric and infrared thermal scanning), coupled with detailed ground measurements of waste effluent concentration, temperature and velocity patterns, were undertaken on the lower Fox River at the Kimberly Clark Paper Mill in Kimberly, Wisconsin. From these observations, a method for relating surficial, suspended solids concentrations to aerial film density was developed and tested, and the patterns and rates of horizontal and vertical mixing and spreading of the discharge were determined.

A general mathematical model for predicting effluent concentration distributions in the mixing zone has been formulated and is being implemented and tested with field measurements. Reports of the field measurements and analysis of results from the surveys at seven sites in previous summers, noted above, are being prepared.

## INTRODUCTION

Increasing concern with pollution of our streams, rivers and lakes has led to considerable public and governmental attention to this problem within the last few years. The Federal Water Pollution Control Act of 1965 (Water Quality Act) and the subsequent development of state water quality guidelines are an outgrowth of this concern. The present State of Wisconsin water quality guidelines (as well as those of other states), regarding the determination of whether discharge of a foreign substance (i.e., biological, chemical or heat) is polluting a stream, river or lake, are somewhat arbitrary in that little consideration appears to be given to the type of effluent, the local flow conditions in the receiving water body, and the type and location of outfall structure.

When a pollutant is introduced into a river, lake or stream, the energy of the effluent discharge and of the receiving water body interact to disperse the substance, thereby reducing its concentration. This dispersal of a pollutant can be envisioned as a two-stage process. In the first region (immediately downstream from the point of discharge), the pollutant is dispersed by the interaction of the physical and flow characteristics of the effluent (i.e., buoyancy, momentum, etc.) and outfall (surface, shoreline, etc.) with these same characteristics in the receiving water body. The first region extends to a distance where the initial physical and flow characteristics of the effluent and outfall are dissipated by the receiving flow field; further dispersal of effluent in the second region is determined by the natural turbulence and velocity distribution in the receiving water body.

Throughout this two-stage process, the waste effluent concentration is being continually diluted until it reaches the concentration level obtainable by complete mixing over a flow cross section of the water body at the point of discharge (for a river the flow cross section would be the river cross section at the outfall). The extent of a water body over which this degree of dilution occurs is defined as the "mixing zone". Other definitions of a mixing zone, such as the region in which a waste is diluted to a particular concentration, are also used. The new Federal Water Quality Guidelines will probably propose a mixing zone definition based upon the time of exposure of desirable organisms to detrimental waste effluent concentrations.

Basic goals of this research are: 1) to develop an explicit relationship for the extent of the mixing zone as a function of outfall, effluent and water body characteristics, and 2) to apply aerial remote sensing methods to the definition of boundaries and waste effluent concentrations in the mixing zone. This relationship may be used: 1) in establishing definite and rational water quality guidelines; 2) in developing sampling and regulation programs by governmental agencies; and 3) in designing and locating outfalls by industries and municipalities. To accomplish these goals, an integrated program of mathematical and laboratory modeling and field measurements is being carried out.

#### SPECIFIC PROJECT OBJECTIVES

(1) To make ground and aerial measurements of waste effluent concentrations and velocity patterns in the "mixing zone" at various sites throughout Wisconsin.

(2) To use these field observations to define the "mixing zone" and to determine airborne photographic and infrared sensor definition of "mixing zone" boundaries and waste effluent concentrations.

(3) To conduct a series of laboratory model studies, for the purpose of duplicating the "mixing zone" characteristics observed in the field.

(4) To develop a mathematical model of concentration and velocity patterns for an effluent discharged into a water body, taking into account the geometrical, physical and flow characteristics of the water body and effluent.

(5) To synthesize results from field and laboratory observations and from mathematical modeling into a relationship for the extent of the "mixing zone" in terms of known or measurable river, outfall and effluent parameters.

(6) To develop a reasonable sampling and regulation program for waste effluent discharges in cooperation with State and Federal governmental agencies.

## PROJECT RESULTS

During 1972-73, an intensive program of field observations of the spreading and mixing of the effluent discharge from the Kimberly Clark Paper Mill at Kimberly, Wisconsin, into the Fox River was carried out from July 17-20, 1972. Field sampling over the four days from boats included distributions over the water surface and river depth of suspended solids, velocity, temperature and dye; aerial color and color IR photography of the effluent discharge, coordinated with the boat sampling, was taken on one day. Analysis of the water samples for total suspended solids and conductance and reduction of the temperature, velocity and dye data has been completed.

A model has been developed to relate aerial photographic film density to suspended solids concentration; the model is in reasonable agreement with the measurements. Lateral turbulent diffusion coefficients have been obtained from the dye data. Using the temperature, velocity and suspended solids measurements, spreading and mixing of the effluent over the depth and across the river have been obtained. This information is being utilized to understand the mixing zone and its dependence upon outfall, effluent and river characteristics and to develop quantitative methodology for monitoring effluent concentrations in the mixing zone.

A general mathematical model for predicting effluent concentration distributions in the mixing zone has been formulated and is being prepared; one of these reports has been completed and submitted to the State D.N.R. Specific results from each phase of the project are discussed below.

### A. Field Studies

During the summer of 1972 extensive field measurements of the effluent discharge from the Kimberly Clark Paper Mill in Kimberly, Wisconsin, into the Fox River were conducted from July 17-20. On July 18 the survey consisted of simultaneous boat and aerial photographic measurements from 3:30-7:00 p.m. of the distributions of temperature and suspended solids on the river surface due to the effluent discharge. On the other three days the surveys consisted of boat measurements of the distributions of suspended solids, velocity, temperature and dye over the depth, width and length of the region affected by the effluent discharge.

The general characteristics for each of the four days of surveys are listed in Table I. Data from the boat observations of these surveys has been reduced and is undergoing interpretation. In addition this ground data has been used as ground truth for the aerial photographic survey.

The Kimberly Paper Mill discharges from a total of 25 outfalls into the Fox River. Four of the outfalls are located upstream of the Cedars Dam (see Figure 1). The remaining outfalls are located just below the dam; their discharges combine into one effluent plume which travels downstream along the south bank of the river. Approximately 65% of this discharge can be attributed to the main mill outfall, a U shaped conduit having an area of roughly  $3.2 \text{ ft}^2$ . The plant discharges about 50,000 lbs/day of effluent which is composed of titanium dioxide, aluminum dioxide, crushed paper fiber and process cooling water. The survey site itself is bounded by the Cedars Dam on the east and the Little Chute Dam on the west. The river widens from 600 ft to 1000 ft in this reach and curves southward. The depth varies from 5 ft to 10 ft. The length of this stretch of river is approximately 0.75 miles.

Ground observations were acquired using two boats, having velocity, temperature and other sensors mounted off the bow. Boat (and sample) locations were determined by angular intersection of transit sightings from two (or three) known shore stations along the river. Velocity was measured using a Gurley cup-type meter. Measurements were taken at several vertical cross sections throughout the discharge plume. Cross sections were unevenly spaced downstream so that major variations in the effluent plume could be studied. The same cross sectional locations were used on all four survey days. Velocity observations were made at the surface and at one-foot depth intervals over the river depth. This data has been reduced to the form of velocity contours (as an example see Figure 2), located in planes perpendicular to the flow direction. Using these plots the discharge within the effluent boundary was calculated. The variation of this discharge with distance from the plant is shown in Figure 3 and compared with results from the previous summer. Also shown in Figure 3 is the variation of the surface width of the effluent with distance downstream of the plant for the same surveys.

Temperature was measured using a Whitney underwater thermometer. The same cross sectional setup was used so that at each velocity measurement there was a corresponding temperature measurement. Temperature observations were reduced using exactly the same method as was used for velocity (an example of temperature contours over a cross section of the discharge is shown in Figure 4). From this reduced data, the heat flux has been calculated for each of the cross sections.

TABLE I     KIMBERLY-CLARK PAPER MILL FIELD SURVEY GENERAL CHARACTERISTICS

Date	$Q_r$ (cfs)	$Q_o$ (cfs)	$T_R$ (°C)	$T_E$ (°C)	Suspended Solids (lbs/day)	Local Climate
7/17/72	2021	17.5	25.0	38.8	52,600	Rainy and Cool
7/18/72	1781	16.9	24.0	38.8	45,500	Light Clouds and Calm
7/19/72	1822	15.5	24.0	38.0	62,500	Sunny and Light Wind
7/20/72	2142	18.0	24.8	38.0	66,500	Sunny and Humid

## KIMBERLY MILL SITE OUTFALL LOCATIONS

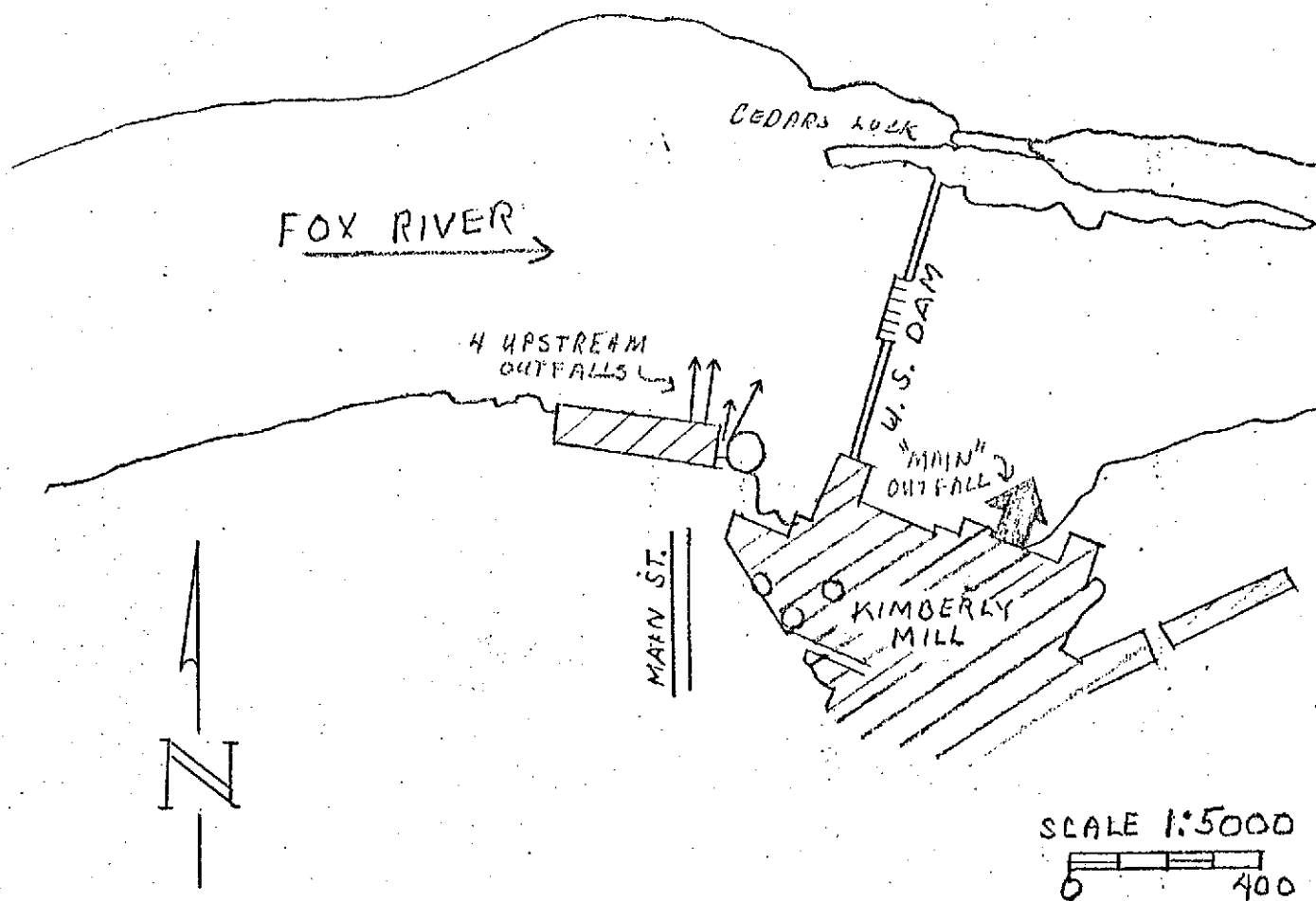


FIGURE 1.

Dye studies were also carried out, using Rhodamine WT dye as a tracer, to determine turbulent diffusion (mixing) coefficients in the river. Dye was introduced at a steady rate on the river surface at three points along the river (two outside and one inside the effluent discharge) from a moored boat. The vertical (over the depth) and lateral (across the river) distributions of the resulting dye concentrations were measured at three sections downstream of the injection point. Dye concentrations were determined by pumping water continuously through a fluorometer, mounted on the boat, while the boat crossed the dye plume (in a direction perpendicular to the plume axis). Turbulent diffusion coefficients were determined from the rate of spread of the dye plume.

Finally an extensive suspended solids sampling program was included in each of the surveys. Water samples (200 ml) were taken simultaneously with the velocity and temperature measurements. Using standard laboratory techniques, total and volatile suspended solids concentrations and sample conductivity were determined. Cross sectional and surface distributions of suspended solids have been plotted and analyzed to determine the flux of suspended solids and its variation along the discharge.

Preliminary conclusions based on data reduction and analysis to date indicate:

(1) near the plant the 21 outlets mix together by entrainment;

(2) beyond 200-300 feet downstream of the plant turbulent diffusion and channel geometry govern mixing; and

(3) vertical mixing is not sufficient to produce uniform temperature and suspended solids concentrations in the first 1000 feet from the outfall.

#### B. Photographic Studies

Microdensitometric analysis of the photography of the Neenah-Menasha STP outfall survey in a previous summer suggested a very probable correlation between image densities and the level of concentration of suspended solids in the surficial layer (top 0.5 ft) of the mixing zone. It was decided to pursue the validity of the correlation by more intensive measurements at the Kimberly Clark Paper Mill site. Consequently, an aerial photographic survey was conducted during summer 1972. It was taken simultaneously with the boat survey on July 18 and covered the period 3:30-7:00 p.m. Photographic coverage included 9 x 9 in format color and color infrared photographs plus supplemental coverage with 35 mm and 70 mm color and color infrared. Some thermal imagery was also taken.



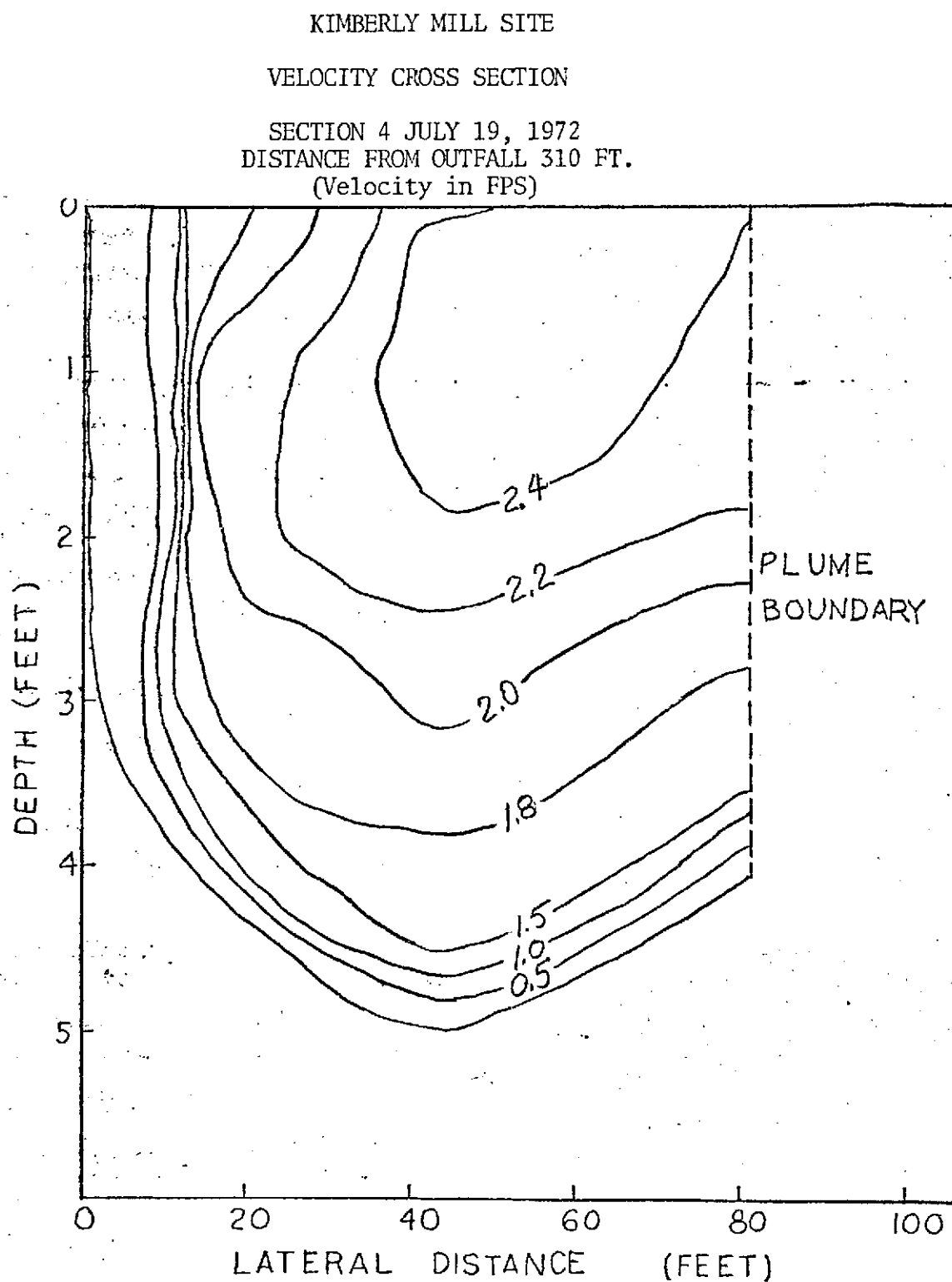


FIGURE 2.

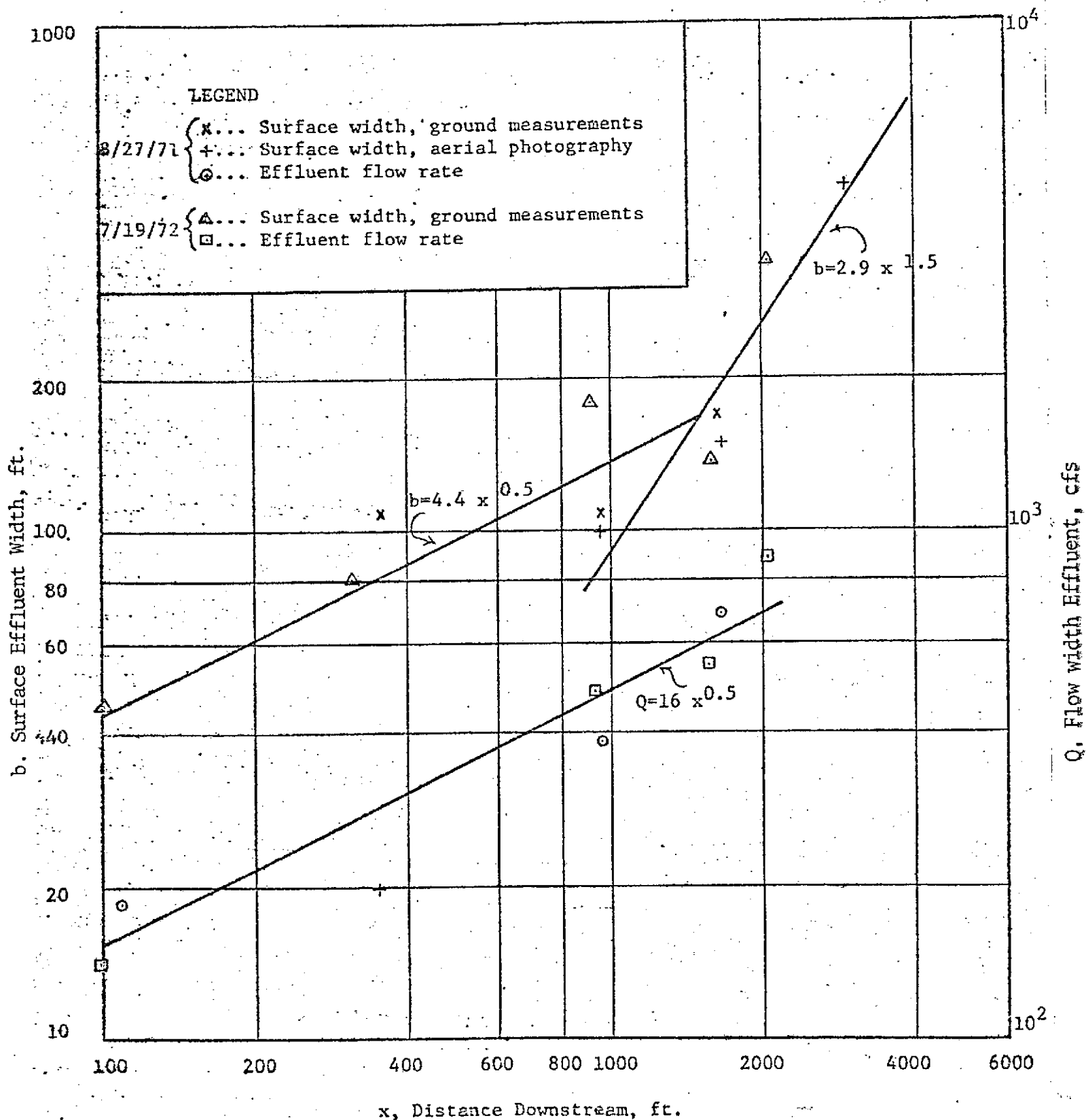


FIGURE 3. Distance from outfall versus mixing zone width and discharge for the Kimberly Clark Paper Mill on August 27, 1971, and July 19, 1972.

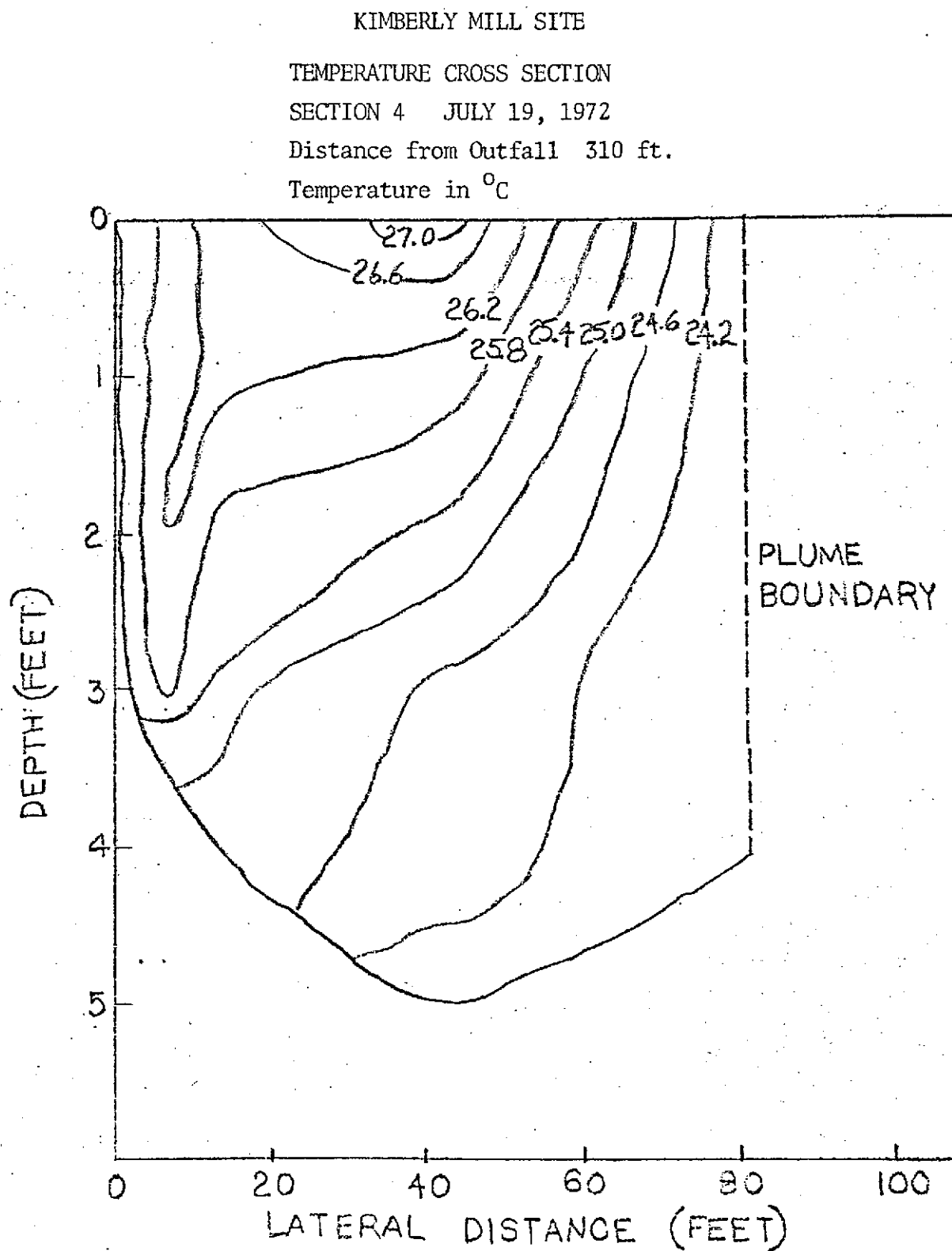


FIGURE 4.

In order to relate suspended solids concentration to photographic image density a model was developed as outlined below. Laboratory reflectance is a function of turbidity and the related suspended solids found in samples taken from the Kimberly Clark mixing zone and ambient regions. From these data it can be shown that for a given wavelenth and for solids concentrations less than about 200 mg/l, the relationship takes the form,

$$R = K_1 S + K_2 - - - - - (1)$$

where  $R$  is the water sample reflectance,  $S$  is the concentration of suspended solids in mg/l, and  $K_1$  and  $K_2$  are parameters.

The film exposure can be related to scene reflectance by the expression,

$$E = K_3 R + K_4 - - - - - (3)$$

where  $E$  is the exposure of the film,  $R$  is the scene reflectance, and  $K_3$  and  $K_4$  are also parameters.

The image optical density resulting from relative film exposure can be determined on the basis of a film-step wedge calibration. The resulting functional expression can take the form,

$$D = B_0 + B_1 A + B_2 Z^2 + B_3 Z^3 - - - - - (3)$$

where  $D$  is the image optical density;  $B_0$ ,  $B_1$ ,  $B_2$ , and  $B_3$  are film type, handling, and processing parameters; and  $Z$  is equal to relative Log  $E$ .

Equations (1) through (3) permit the development of an expression (model) which permits the estimation of suspended solids,  $S$ , from the measurable image density,  $D$ , so that,

$$S = a 10^{Z(D)} + B - - - - - (4)$$

where  $a$  and  $B$  are model parameters and  $Z(D)$  results from the solution of equation (3).

The model manifested by equation (4) was used in the study of the Kimberly Clark Paper Mill mixing zone. The image optical densities were extracted from each of the three layers (red, green, and blue) of color infrared film type 8443. Concurrent with the aerial photography, suspended solids water samples were taken in the surficial layer at 82 locations. A photogrammetric solution for the image position associated with each sample location provided a viable means for obtaining simultaneous image densities and solids concentration.

The image densities were digitally recorded using a scanning microdensitometer system, which permitted discrete density observations over film areas depicting about 1.33 ft square areas on the ground. Experience showed that the image densities could be grouped into 36 density levels to give satisfactorily refined density observation (about 0.08 density units).

Equation (3) was solved for each observed density for corresponding values of  $Z$ . The  $B$  parameters were estimated from the  $D$  versus  $\log E$  curves resulting from the film calibration work. The suspended solids data resulting from the samples taken at the 82 locations were then used with these  $Z$  values to determine the  $a$  and  $B$  parameters. In both instances above, the curve fitting was done by least squares methods.

Figure 5 is a plot of the observed suspended solids and film density data. Also shown are the model predictions using a solution of equation (4). It is believed that the scatter of the data is due largely to the experimental errors in obtaining and analyzing the water samples.

The model (equation (4)) can be used with confidence for this particular mixing zone, provided the  $a$  and  $B$  parameters are determined for each roll of film. The applicability of this method to other types of suspended solids and mixing zones needs to be evaluated.

Based on the results and experiences of this work herein the following conclusions have been drawn:

(1) Photodensitometric variations on the color infrared imagery systematically reflect the surficial distribution of suspended solids throughout the mixing zone.

(2) The suspended solids/density model as developed and implemented herein can be used to measure surficial suspended solids concentrations as reliably and in more detail than conventional surface measuring techniques.

(3) The suspended solids/density model as developed and implemented herein is theoretically limited in its utility to the range of suspended solids concentrations of from 0 to 200 mg/l.

### C. Mathematical Modeling

Using the equations of mass, momentum and heat conservation, a general mathematical model has been formulated describing the concentration and velocity distributions in the mixing zone of a waste effluent discharged into a surface water body.

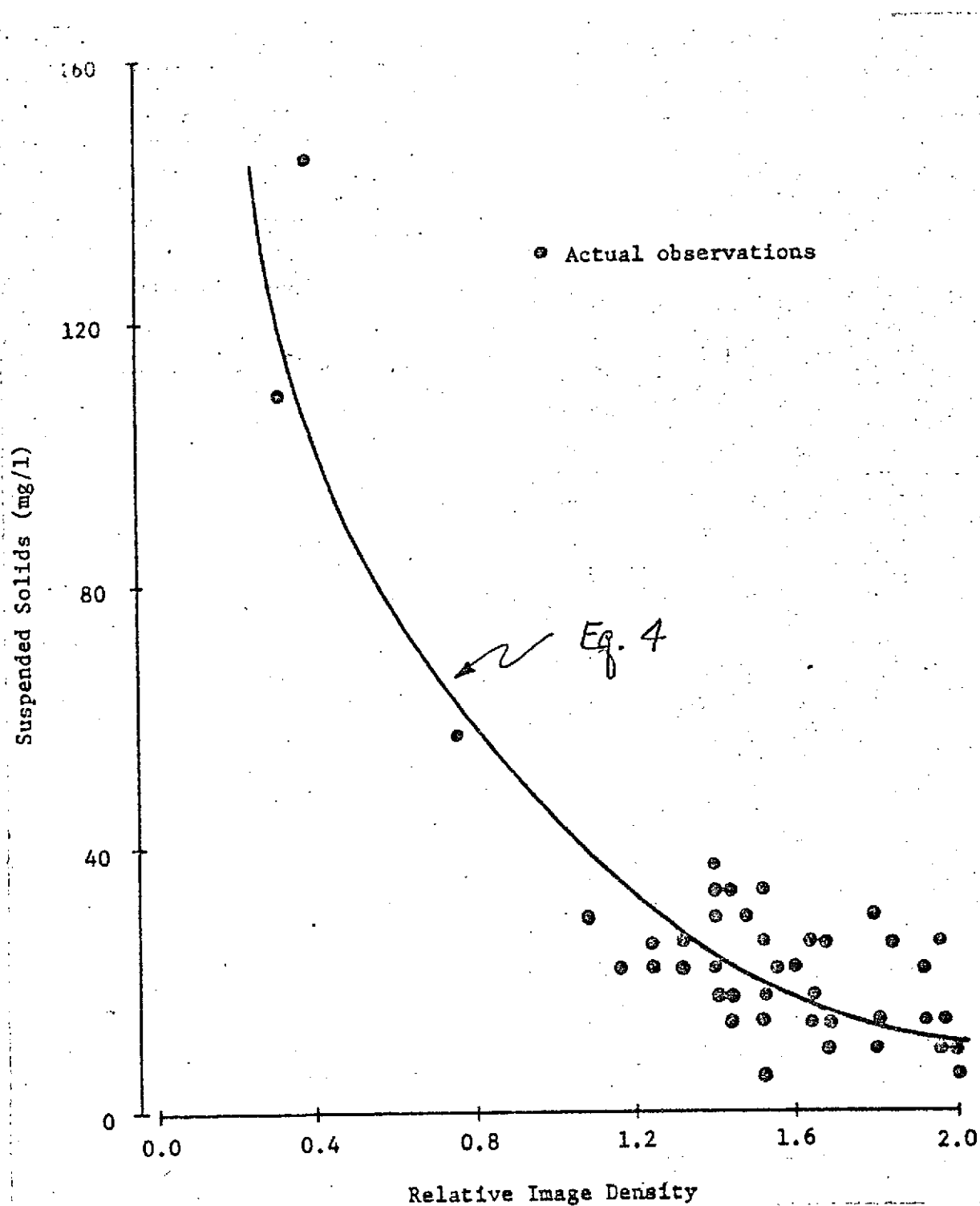


FIGURE 5. Observed suspended solids versus relative image density for the Kimberly-Clark Paper Mill mixing zone on July 18, 1972.

In the initial region of the mixing zone -- where the momentum and buoyancy of the effluent play are important in the dilution process -- a one-dimensional scheme is used in which the center-line velocity, concentration and trajectory changes with distance from the outfall are predicted.

In the second region of the mixing zone -- where velocity and turbulence distributions of the ambient water body govern the subsequent dilution -- a three-dimensional model is used. The mathematical model has been programmed for numerical solution; work is continuing on determination of coefficients and parameters (i.e., diffusion coefficients, entrainment coefficients, etc.) from field data and the work of others and on verification of the model.

In addition, simple two and three-dimensional, source type models are being compared with previous observations from the seven survey sites in order to estimate the extent of the mixing zone and to determine diffusion coefficients.

#### D. Other Activities

Concurrent with the field observations and the data analysis of the Kimberly Clark Paper Mill surveys, the mixing zone personnel are preparing reports of the field measurements and interpretation regarding the mixing zone for surveys carried out over the past three years at seven sites throughout the State. One report, dealing with the effluent discharge from the Consolidated Paper Company in Wisconsin Rapids into the Wisconsin River, has been completed and sent to the Department of Natural Resources of the State of Wisconsin. The remaining reports are being completed.

In June 1973, a paper, "Remote Sensing in the Mixing Zone", was presented at the American Water Resources Association International Symposium on Remote Sensing of Water Resources in Burlington, Ontario. This paper, which will be published in the conference proceedings, gives an overview of project goals and activities, together with a conceptual discussion of the mixing zone definition and aerial and ground measurements associated therewith.

#### FUTURE PLANS

While the development of (1) the explicit relationships for the extent and shape of the mixing zone, and (2) the methodology to apply remote sensing to the definition of the boundaries and concentrations of the mixing zone remain the long term objectives of this project, we recognize the necessity to provide interim solutions to current aspects of the mixing zone problem based upon the best available information. Therefore, we intend



to focus the 1973-1974 research effort towards the specific interim objectives:

(1) To establish a rational statement of mixing zone criteria for incorporation into water quality guidelines as established by the State of Wisconsin.

(2) To establish procedures for the engineering design of new outfall structures.

(3) To determine the relative concentrations within a plume and, based upon this, determine at what point or points personnel of the DNR monitoring program should obtain samples in order to establish the degree to which mixing zone criteria are being met.

(4) To develop and demonstrate a mixing zone monitoring system capable of covering large geographic areas which will meet the DNR surveillance mission.

To accomplish these objectives, we propose:

(1) to complete documented field reports for the seven sites surveyed over the past three field seasons (one site report is already completed);

(2) to develop an integrative report based upon the field report above, and the mathematical modeling and mixing zone laboratory studies. This integrative report shall be directed specifically towards objectives (1) through (3) above at a state of the art level;

(3) to complete the general mathematical model of the mixing zone to the state of the art level;

(4) to establish and demonstrate procedures for remote sensing of surface concentrations within the mixing zone (particularly the aerial photographic technique developed in 1972-1973 for monitoring the Kimberly Clark Paper Mill effluent);

(5) to apply these remote sensing procedures to evaluate the effectiveness of the modified Kimberly Clark Paper Mill waste treatment procedures;

(6) to work with Dr. Francis H. Schraufnagel, Mr. Carroll Besadny, Mr. Kenneth H. Beghin and the appropriate offices of DNR towards the implementation of (2) and (3) above, at least on a demonstration basis; and

(7) To inform Mr. Jerome R. McKersic, Chief, Water Quality Evaluation, DNR, and Mr. Duane H. Schuettelpelz, Environmental Engineer for DNR, of the progress of the project and to provide them information for updating standards when possible.

## V. APPLICATION OF REMOTE SENSING TO THE LOCATION OF HYDROLOGICALLY ACTIVE (SOURCE) AREAS

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### ABSTRACT

At present, the source area concept is still a hypothesis. However, the concept has recently received strong support, and a technique for determining these areas in the field is needed. Identification of these areas in a watershed will help not only in developing a more accurate "runoff generation model", but will also have numerous uses in areas of statewide concern such as water quality, trout stream classification, rural drainage, erosion and soil conservation. Since identifying these areas by conventional field methods would be extremely time consuming and expensive, development of remote sensing identification systems is an attractive alternative. To pursue this alternative, a comprehensive study including hydrologic investigations and color I.R. images of the Lowery Creek watershed in Wisconsin is underway. Initial results of the analysis are very encouraging. In the remote sensing imagery obtained thus far (one set of color and four sets of color I.R.), areas of known high soil moisture (probable source areas) are prominent. This tonal difference is more marked on bare soils than vegetated ones. To complement the remote sensing efforts, field studies have been established at probable source areas to investigate depth variation of soil moisture with time. In addition, streamflow and precipitation monitoring sites have been established. Maps of the source areas are currently being prepared. Initial contacts have been made to promote applications of the method by state and federal agency groups.

### A. SOURCE AREA CONCEPT

#### 1. Hydrologic Factors

Recently a hypothesis generally known to hydrologists as "source area concept" has gained considerable attention and theoretical support through the efforts of many engineers and hydrologists (Hewlett 1961; Betson and Marius 1969; Dickinson and Whiteley 1970; Hewlett and Nutter 1970; Dunne

and Black 1970; Hills 1971; Freeze 1972). Common to all these authors' concepts is a recognition that surface and subsurface runoff is geographically concentrated at hydrologically active portions of a basin. In essence, this concept includes two simultaneous processes which together produce storm runoff:

- (a) The perennial channel system expands and extends into zones of low storage capacity and directly intercepts precipitation which is rapidly incorporated into stream-flow.
- (b) The expanding channel system is fed by subsurface flow, which enters at a slower rate than direct runoff, but may be responsible for the bulk of storm flow in many cases.

## 2. Significance

Identification of hydrologically active source areas is important for the following general reasons:

- (a) Water quality: Zones of high water flux will tend to rapidly lose fertilizers or pesticides to streams draining the area, therefore identifying these areas is a key to regulating diffuse sources of stream contaminants.
- (b) Rural drainage: In general, source areas are portions of a watershed that are unsuitable for rural drainage, since they are expected to be near saturation more often than adjacent areas. Thus a general source area map would provide useful information to farmers and other interested parties in planning locations for the disposal of waste water on farmsteads. According to county agents in Wisconsin, this is a very important problem in rural areas at present.
- (c) Erosion and soil conservation: Conservation practices are most effective when applied to critical basin areas. However, in many cases, problem zones are accessible only with great difficulty, making reconnaissance expensive and time consuming. It is expected that the extent of source areas in the neighborhood of a stream has a direct relationship to the stability of stream banks, hence it is felt that problem areas where remedial action is needed can be located by identifying the source areas through remote sensing methods with a good savings in manpower, time, and money.
- (d) Water and land management: Identification of source areas will enable the determination of uses best suited to their physical and chemical properties.
- (e) Classification of trout streams: Critical positions in

streams where trout spawning and favorable habitat occur are known to be associated with springs, seeps and groundwater discharge. These areas in turn are related to the source areas and, it is hoped, may be located using remote sensing surveys. The information from such surveys is of interest to regulatory agencies for management purposes.

## B. PRESENT RESEARCH

### 1. Basin Selection

Results of initial attempts to locate source areas using 9" x 9" black and white aerial photographs were reported in the 1971-1972 progress report. Since then, the Lowery Creek, Wisconsin watershed has been chosen for more comprehensive studies.

This watershed is located in Iowa County, Wisconsin, is about forty miles west of Madison, and is a tributary to the Wisconsin River. Iowa County is one of fifteen counties related environmentally by being an integral part of the "Driftless Area" of Wisconsin. In general this is an area of ridges and valleys that cut into very gently dipping sedimentary rock. The interbedded sandstone and dolomitic limestone formations in this area dip very gently in the soil. All of the plain and many of the valley slopes are covered with soil mantle up to a maximum of ten feet in thickness with two to four feet as an average. It is characterized by streams that respond rapidly to intense storms, and is thus thought to be a good location for initial source area characterization studies. Though the Lowery Creek basin covers an area of about twenty square miles, only the headwaters (seven square miles) of this basin have been considered. A map of the study area is shown in Figure 1.

### 2. Hydrologic Data

Streamflow: One of the basic data sets required in connection with this research is a continuous record of streamflow. To gather this data, a facility had to be constructed. A type "HL" flume with supporting structures (designed by U.S. Soil Conservation Service for small watersheds) was constructed for the study. The flume design was selected to provide accurate flow monitoring over the wide range of flow rates expected during the project. Approval for the construction was obtained from the Wisconsin Department of Natural Resources. The structure is shown in Figure 2. A Friez-Bendix water level recorder was installed on March 15, 1973 and streamflow has been recorded since then. A discharge rating table for the HL flume is given below.

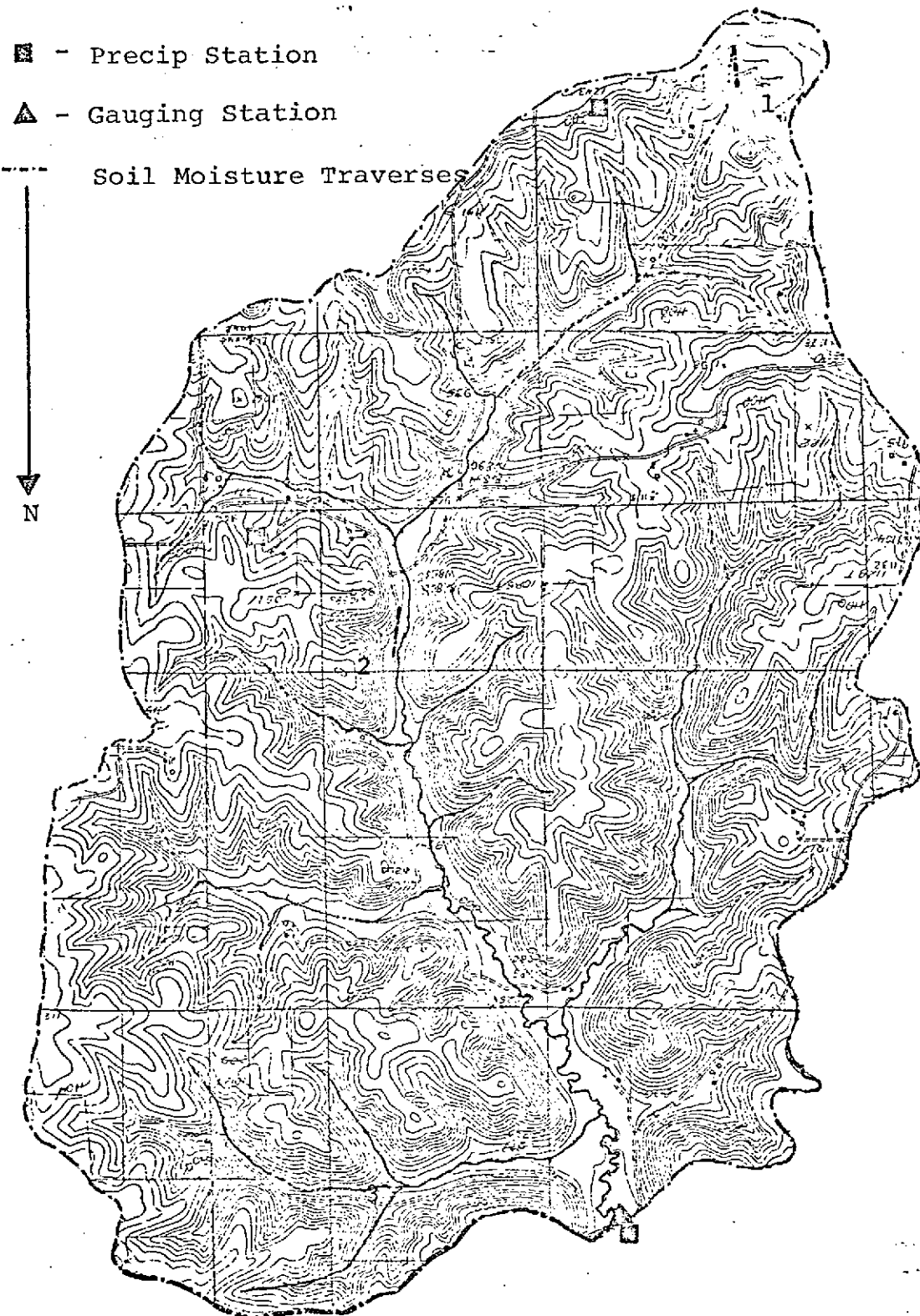


Figure. 1. - Lowery Creek Watershed showing the Gauging Station and the Precip Stations

Head in feet	Discharge in cfs	Head in feet	Discharge in cfs
0.05	0.03	1.20	8.06
0.10	0.09	1.40	11.20
0.20	0.28	1.60	14.90
0.30	0.56	1.80	19.20
0.40	0.96	2.00	24.3
0.50	1.42	2.50	39.9
0.60	2.01	3.00	60.3
0.80	3.53	3.50	85.9
1.00	5.56	4.00	117.00

Discharge Rating Table for Type HL Flume

**Precipitation:** In order to record spatial and time variations in quantities of basin precipitation, three Bendix Model 775C rain and snow recording gauges have been installed at the locations indicated in Figure 1. Precipitation data charts will give time resolutions to 15 minute increments where necessary. This detail is required to establish quantitative relationships between precipitation, stream-flow, and the areal extent of the basin source areas.

**Soil Moisture Measurement:** Two traverses (indicated in Figure 1) across source areas that have been identified from the analysis of I.R. imagery have been chosen for the study of temporal variation of soil moisture laterally and with depth. Aluminum tubes (2 inch outside diameter) have been inserted to bed rock along traverse 1 and are to a depth which is about a foot below the water table in traverse 2. Soil water content is determined on a regular basis at each tube location. A Troxler neutron moisture gauge has been obtained for this purpose. This apparatus consists of two principal parts:

- (a) a probe (Troxler Model 1352) which is lowered into the access tube inserted vertically into the soil, and which contains a source of fast neutrons and a detector of slow neutrons;
- (b) a battery-powered scaler or ratemeter (Troxler Model 1255) to monitor the flux of slow neutrons, which is proportional to the soil water content adjacent to the neutron source. It is anticipated that the soil moisture data will be of major value in relating I.R. imagery to the extent of source areas.

### 3. Remote Sensing

The first set of imagery (color and color IR) using a 35 mm camera was obtained on April 25, 1973. The 9" x 9" mapping camera was used for the second and third sets of flights for IR imagery on May 31, 1973 and August 20, 1973. The fourth set of IR imagery was obtained on October 4, 1973 using a 35 mm camera. Flying heights of 3,100 feet and 4,500 feet above MSL, respectively, were used for the 35 mm camera and 9" x 9" mapping cameras. It is hoped to obtain one set of thermal imagery in the week of October 8, 1973. Photographic (color and color IR) and thermal imageries will be obtained immediately following a major rainfall event to determine the dynamic aspect of source areas. This operation would most probably be performed during late autumn of this year or in the early part of spring in 1974.

In the analysis conducted thus far, areas of high soil moisture (probable source areas) are seen prominently on the color IR imagery. The tonal response is more marked on bare soils than on vegetated ones. This phenomenon is seen in Figures 3, 4 and 5. Currently, efforts are being made to assemble a series of source area maps from the photographs obtained at different times. These maps should indicate the expansion or the shrinkage of these areas, as well as their persistence. Once the maps are completed, the total extent of the source areas will be measured, and work to relate them to streamflow quantities can proceed.

### C. FUTURE RESEARCH PLANS

**Correlation and Verification:** With the soil moisture variation along a preselected traverse in the source areas known, the remote sensing imagery will be correlated to the observed runoff areas, thereby monitoring the shrinkage or expansion of the source area with time. The technique to be studied will involve using the scanning microdensitometer on the imagery and then drawing contour lines on the digitized printout. Areas of equal tonal response will be marked and compared with results from ground truth observations to evaluate the method.

In conjunction with source area quantification, a hydrologic model based upon the source area concept will be developed. The conceptual framework has been established, and the model will be programmed and tested as sufficient data become available.

### D. APPLICATIONS OF EARLY RESULTS

Three specific applications are to be explored with various state and federal agencies. The identification of streamband erosion potential via associated source areas has been discussed with a few members of the Interagency Red Clay





Figure 2. Streamflow gauging station. Type "HL" flume with supporting structures. Site location is shown in Figure 1.

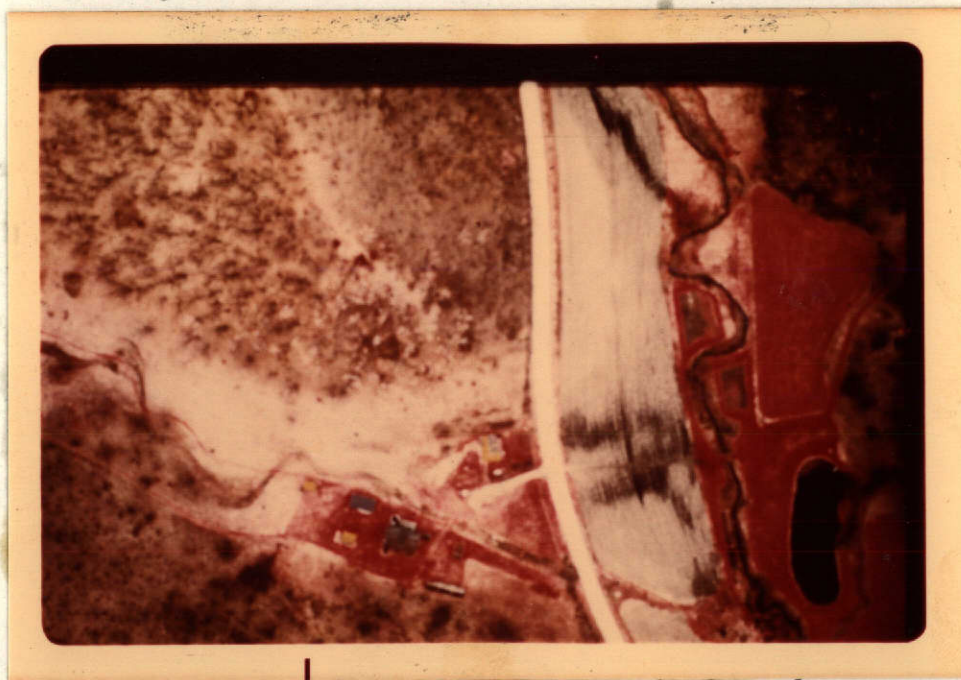


Figure 3. Probable source area is shown in dark gray between the road and stream. Site location of this area is marked 2 in Figure 1.



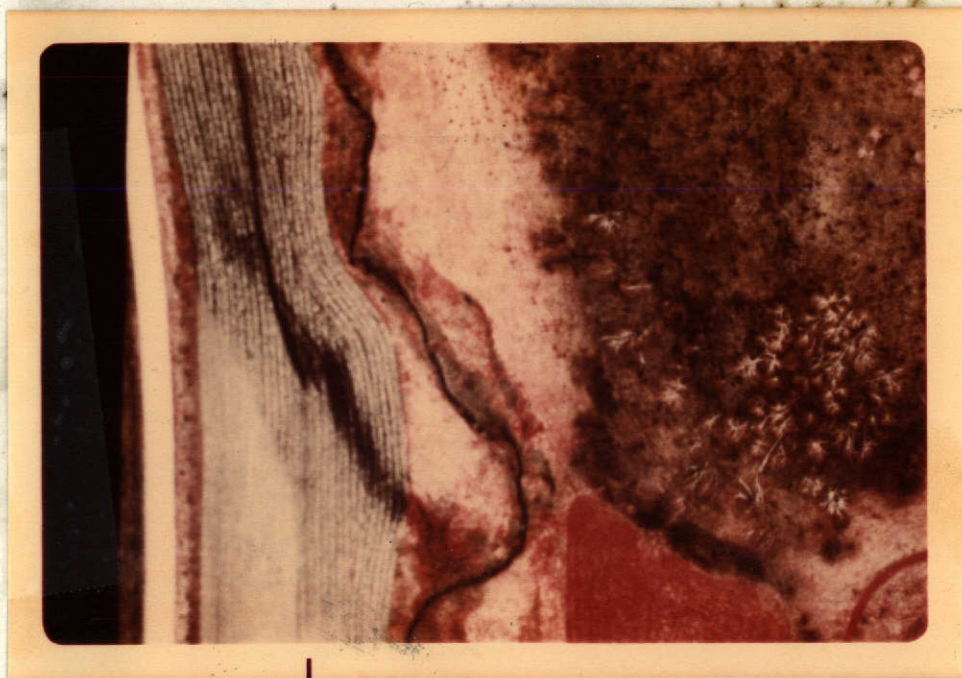


Figure 4. Probable source area shown in dark gray to the left of the stream. The hydraulic connection to the stream too is seen.



Figure 5. Probable source area shown in dark gray between road and stream. Site location is marked 3 on the map in Figure 1.

Committee, and a formal request has been sent to these members to arrange for a presentation of the concept and supporting results to the full committee. When arrangements have been completed, the presentation will focus on establishing a cooperative pilot study using the technique for surveying potential erosion sites. The initial discussions are encouraging, and it is hoped that a hearing can be obtained by early 1974. The same committee has interest in the rural drainage question, so that point will also be suggested at the meeting.

Only preliminary discussions have been held with Wisconsin Department of Natural Resources fisheries staff regarding a survey for trout stream classification. It is intended that these discussions continue; and a field trip will be suggested when the source area mapping is complete enough to identify several likely locations in the Lowery Creek basin. It is felt that it is important to be able to positively demonstrate the potential of the method before attempting to involve the DNR personnel.

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## VI. AQUATIC ECOSYSTEMS ANALYSIS

### A. REMOTE SENSING OF AQUATIC MACROPHYTES

#### Principal Investigator:

Michael S. Adams, Associate Professor, Department of Botany

#### Research Assistant:

Todd Gustafson, Graduate Student, Department of Botany

### BACKGROUND

Ecological investigations of aquatic systems are especially difficult and time consuming. Aerial photography and other remote sensing techniques may in part fulfill the need for the development of more rapid and accurate methods for investigation of aquatic plant communities.

Our previous studies demonstrated that the aquatic macrophytes in Lake Wingra could be imaged on color and color infrared film and suggested that community and species types could be differentiated. The results of the initial quantitative techniques utilized during the 1971-72 period provided encouragement for an effort to develop methods correlating image densities with quantitative parameters of the aquatic vegetation.

The past year's effort concentrated on the development and refinement of aerial photographic methods for the recognition mapping, and analysis of aquatic macrophyte communities. Lake Wingra was the main study site but Fish Lake in northern Dane County, Wisconsin was used for validation purposes.

### IDENTIFICATION AND MAPPING

Lake Wingra is a shallow, highly eutrophic lake where the littoral macrophyte communities are presently homogenous stands of a single dominant species. The distribution of these communities is primarily the result of substrate composition, water depth, and in some cases, storm sewer input of plant nutrients. The pure stands plus the fact that most of the plants grow to or very near the surface allows aerial photography to be the method of choice for studies requiring rapid yet detailed assessment. The vegetation map of 14 July 1971 (Figure 1) was prepared from 35 mm color infrared photographs and demonstrates the detail remaining in spite of the synoptic perspective. An identification

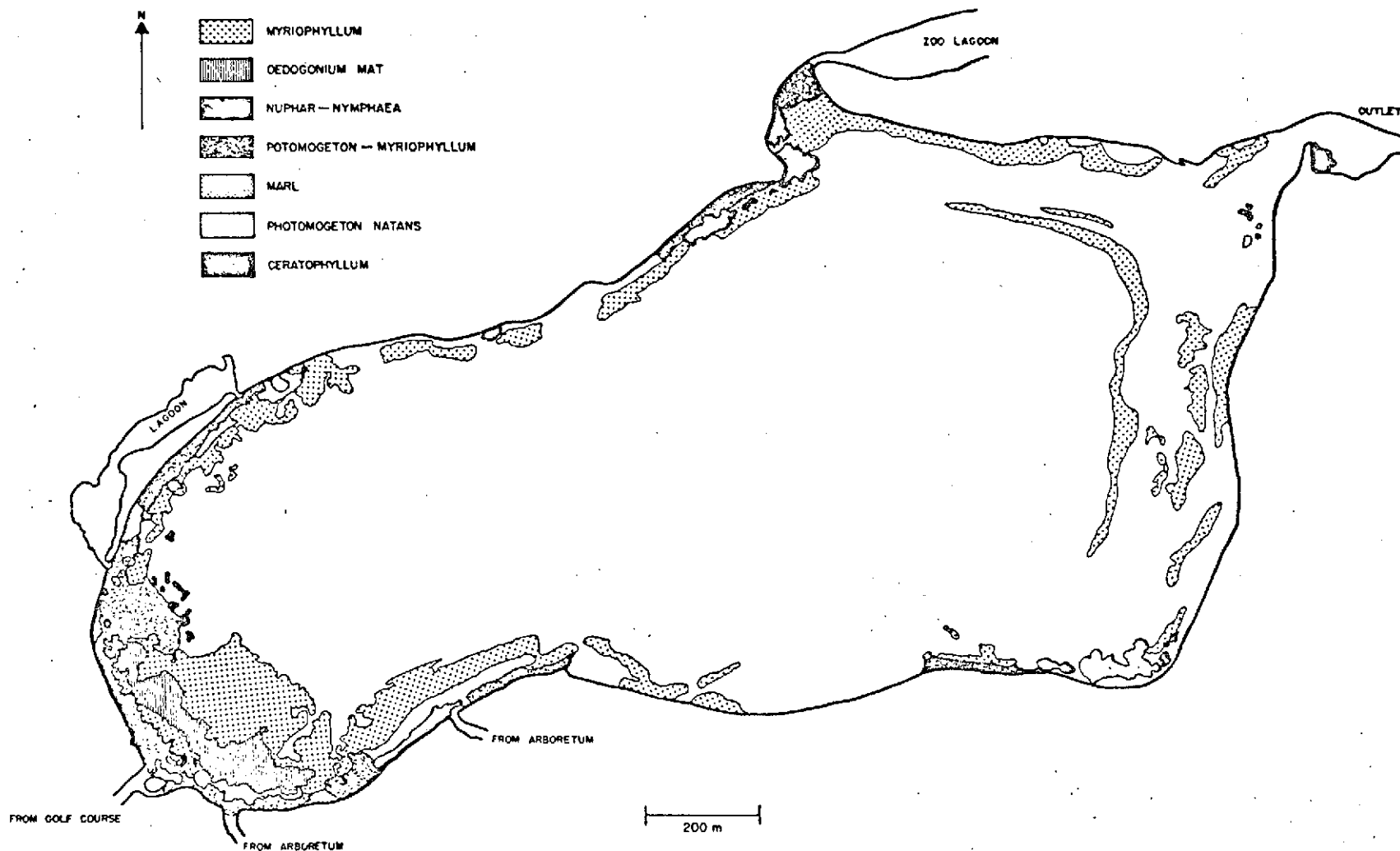


Figure 1. Lake Wingra vegetation map of 14 July 1971. Map was constructed from aerial color infrared photographs by using projection techniques.



TYPE	TONE	TEXTURE	LOCATION	SHAPE	MUNSELL COLOR	DENSITY RATIO
MYRIOPHYLLUM	DEEP ORANGE	MOTTLED	MID TO DEEP LITTORAL (70-270 cm)	VARIABLE, BOUNDARIES DISTINCT	7.5R7/10	0.9306
NUPHAR- NYMPHAEA	BRIGHT PINK	FINELY TEXTURED	PROTECTED AREAS SHALLOW TO MID LITTORAL (35-80 cm)	ROUND TO ELONGATE	2.5RP8/6	0.8843
OEDOGONIUM MAT	VERY LIGHT TAN	VERY SMOOTH	OVERGROWTH ON MYRIOPHYLLUM	AMORPHOUS, BOUNDARY INDISTINCT	7.5R9/12	1.0416
CERATOPHYLLUM	DEEP RED	UNIFORM TO ROUGH	EDGES OF MYRIOPHYLLUM BEDS	VARIABLE	7.5R3/12	0.8027
POTAMOGETON- MYRIOPHYLLUM	DARK GREEN	UNIFORM	NEAR SHORE LITTORAL	VARIABLE	-	1.8470 (0.728)
FLOATING- LEAVED POTAMOGETON	MEDIUM PINK	COARSE	MID LITTORAL (100-200 cm)	ROUND	7.5R8/6	-
DEEP WATER	DEEP BLUE	UNIFORM	AREAS MORE THAN 3 m DEPTH	-	2.5PB6/8	2.1620 (6.646)
SHALLOW WATER MARL	LIGHT TURQUOISE	UNIFORM	SHALLOW TO MID LITTORAL	ELONGATE WITH SHARP BOUNDARY	2.5PB8/4	-

Figure 2: Identification key for the Lake Wingra image types. Results are for color infrared film (Kodak aerochrome 2443). Density ratios are 600:625 nm except values in brackets which are 450:600 nm.



key for these community types (Figure 2) was prepared for the type 2443 film. Film density ratios were used to include greater precision in the interpretive process. The ratio of 600:625 nm was found satisfactory for most of the image types with the exception of the Potamogeton-Myriophyllum which required an additional ratio of 450:600 to separate it from open water areas (values in brackets). The identification features were determined from photographs of Lake Wingra but were found also applicable to the photography of the aquatic communities of Fish Lake.

Photographic methods for identification and mapping are an especially powerful tool for fresh water resource inventory and the study of lake succession. Their most obvious advantage over conventional methods is the manifold increase in efficiency. Surface surveys using line transects take at least ten times the effort of the photographic techniques and give results which, while in some ways more detailed, are in most respects inferior.

This season's photography of Lake Wingra will provide additional information on the spatial and temporal distribution of the aquatic vegetation. It is anticipated that these results can be used for the testing of biosystem models developed by the International Biological Program at the Lake Wingra Site.

#### QUANTITATIVE ANALYSIS

Color and color infrared exposures were used to visually interpret biomass and stem density classes within the Myriophyllum beds. The color infrared was found superior for the differentiation of image types that were the result of different levels of community vigor. Projection techniques were used to map the distribution of the image types and area measurements made by planimetry. Harvest sampling was used to characterize the image types by their mean stem densities (Table 1) and to calculate the conversion to biomass. Biomass estimates were made by multiplying the area in each class by the mean stem density and total stems converted to total biomass using the appropriate conversion factor.

Optical density measurements of the color infrared film images were used to estimate the standing crops of the Oedogonium mats and the Myriophyllum community. A Gamma Scientific micro-densitometer spectrophotometer was used to sample the respective images using a spot size equal to 2.5 m<sup>2</sup> at the water surface. Good results were obtained by using density values at 600 nm for the Myriophyllum and 555 nm for the Oedogonium. Three methods of photographic standardization were tested for their usefulness in correcting for such variables as sun angle, sky condition, wave state, and water turbidity. The method using a ratio of open water film density and community film density was found superior to methods using reflectance panels on the water surface and density readings at several wave lengths from within the community.

Table 1. Concurrently obtained harvest sampling results used for verification and calibration of photointerpretative method of estimating Myriophyllum biomass in Lake Wingra. The density categories correspond to image classes differentiated in color infrared aerial photography. 95% confidence limits shown for mean stem counts.

Period	High Density Growth (stems.m <sup>-2</sup> )	Low Density Growth (stems.m <sup>-2</sup> )	Mean Wt/Stem (g ash-free)
5/15 - 6/30	300.7 <sup>±</sup> 97.8	140.8 <sup>±</sup> 36.8	1.11
7/1 - 8/15	298.0 <sup>±</sup> 12.8	138.6 <sup>±</sup> 36.4	1.02
8/16 - 9/15	368.5 <sup>±</sup> 52.6	148.6 <sup>±</sup> 48.6	0.90

Harvest sampling of six "test stands" for each type (Tables 2 and 3) was used to test and calibrate the photographic analysis method.

Harvest data was tested against film density analysis data by linear regression with good results (Figures 3 and 4). Biomass or stem density estimates were made by converting the mean film density to mean stem density or biomass using the appropriate regression formula and multiplying that by the stand area obtained by photogrammetry.

Certain features of the growth of Oedogonium and Myriophyllum in Lake Wingra facilitate the successful application of quantitative methods using aerial photography. The use of 555 nm and 600 nm for density analysis is able to provide a uniform and contrasting background for the respective images on color infrared film (Figure 3). Both vegetation types are found in nearly pure stands with good correlation between cover, plant density, and standing crop.

We consider image interpretation to be inferior to photographic analysis for quantitative measurements of Myriophyllum. The limited number of stem density classes and the subjective selection of these classes are potential sources of considerable error. However, when total biomass estimates obtained by photographic interpretation were compared with those of film analysis, the close agreement suggested that photo-interpretative methods may be a suitable alternative to conventional harvest methods.

The advantages of the photographic methods are their efficiency and accuracy. When compared with estimates made using harvest procedures alone, the photographic methods were found to provide data of greater statistical reliability. The large sample size possible with photoanalysis resulted in standard errors much less than 10% of  $\bar{x}$  but those obtained by harvest only were as high as 40% of  $\bar{x}$ . The total biomass estimates of the harvest method were much different from those of the photographic methods. We suspect that difficulties in estimating the exact area sampled while using the harvest method resulted in substantial overestimation of Myriophyllum standing crop. The greatest advantage of the use of photographic methods is their efficiency. The harvesting and sample processing required about 250 hours of work per estimate, while photographic analysis can be accomplished in as few as 10-15 hours. Short term changes that would be completely obscured in the days or weeks required to collect the necessary number of samples can be monitored by photography. The photographic methods also have the advantage of being non-destructive.

Table 2. Harvest data and corresponding raw and standardized image density data that were used for verification and calibration of photoanalytic technique for estimating Myriophyllum biomass in Lake Wingra. 95% confidence limits are shown for mean stem densities.

Stand	Plant Density (stems.m <sup>-2</sup> )	Stand Image Density (600 nm)	Water Image Density (600 nm)	Water Density/ Stand Density
1	255.8 ± 10.1	1.248	2.195	1.759
2	226.6 ± 9.6	1.489	2.183	1.466
3	193.9 ± 15.8	1.713	2.155	1.258
4	189.3 ± 11.2	1.808	2.249	1.244
5	171.6 ± 6.3	1.852	2.261	1.221
6	202.5 ± 11.6	1.566	2.255	1.440

Table 3. Oedogonium harvest data and corresponding raw and standardized film densities that were used to test photographic analysis as a sampling technique for estimating algal mat biomass. 95% confidence limits are shown for mean stand biomass.

Stand and Date	Biomass (g. 0.1 m <sup>-2</sup> )	Image Density of Alga (555 nm)	Image Density of Water (555 nm)	Water Density/ Alga Density
West 8/10/71	8.72 ± 1.9	0.674	1.223	1.815
West 8/24/71	4.24 ± 1.8	0.330	0.418	1.267
West 7/24/72	5.70 ± 1.2	0.962	1.508	1.567
West 9/6/72	5.90 ± 2.7	0.835	1.193	1.429
East 9/6/72	8.03 ± 2.1	0.703	1.057	1.504
South 9/6/72	0.00 -	1.116	1.173	1.051

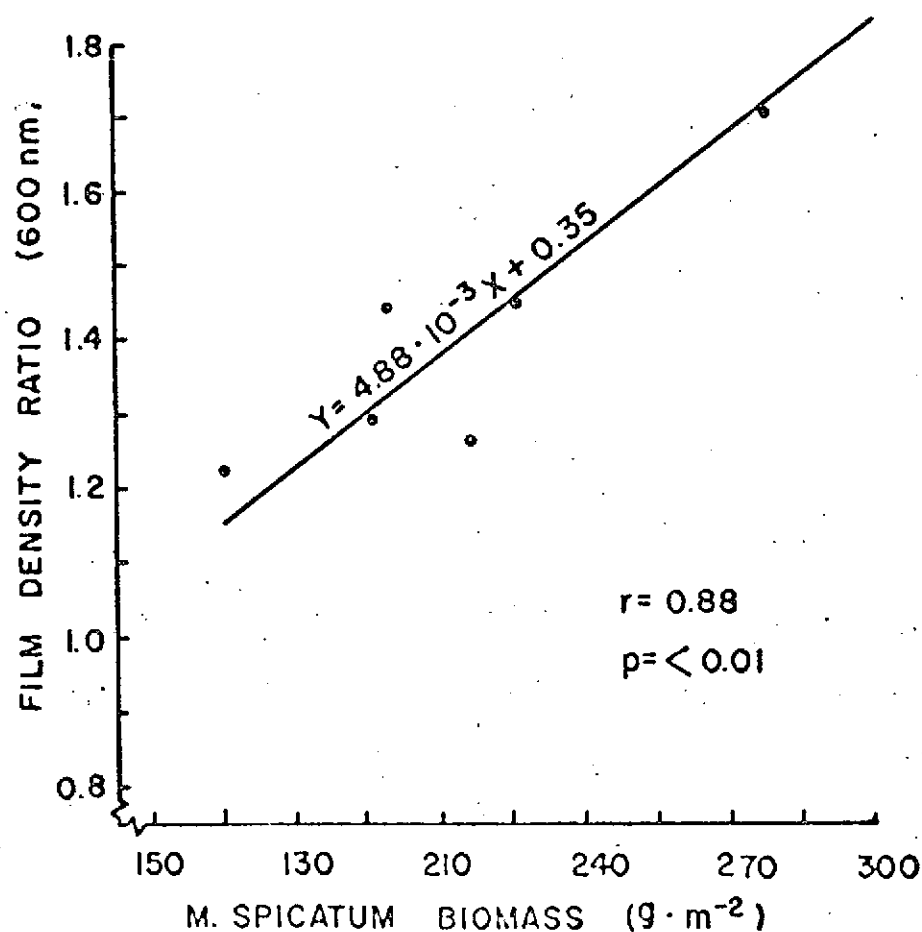
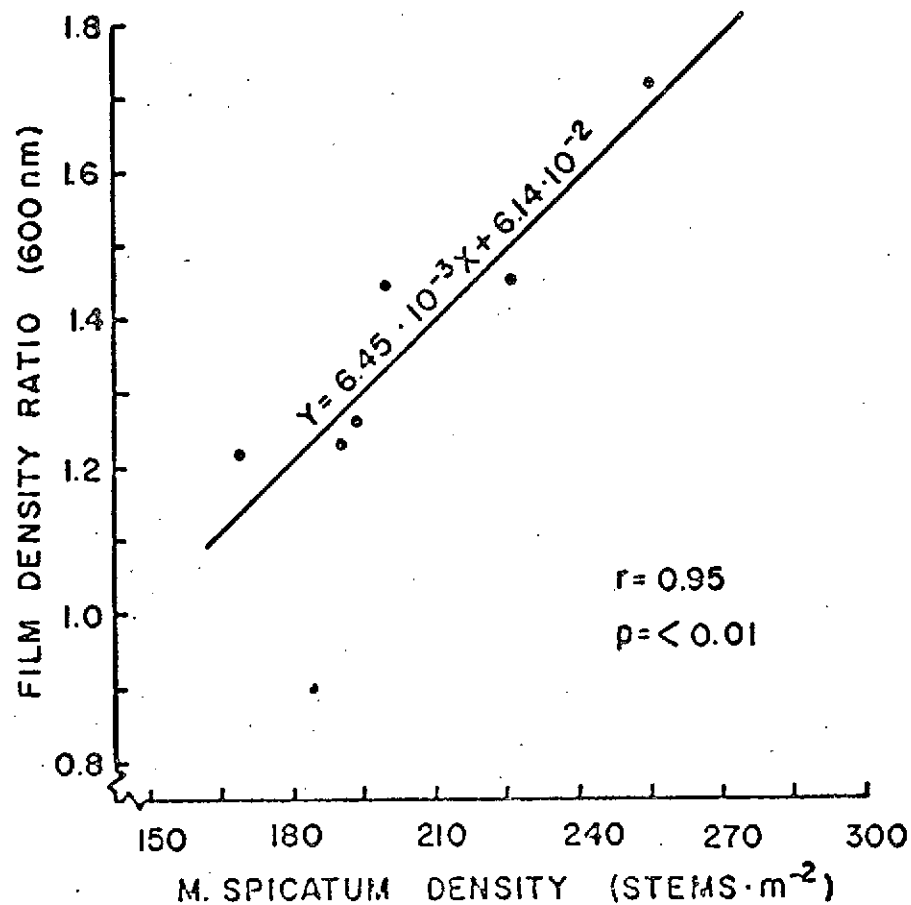


Figure 3. Regression analysis of Myriophyllum harvest data and film densities that were standardized by using readings from open water areas.

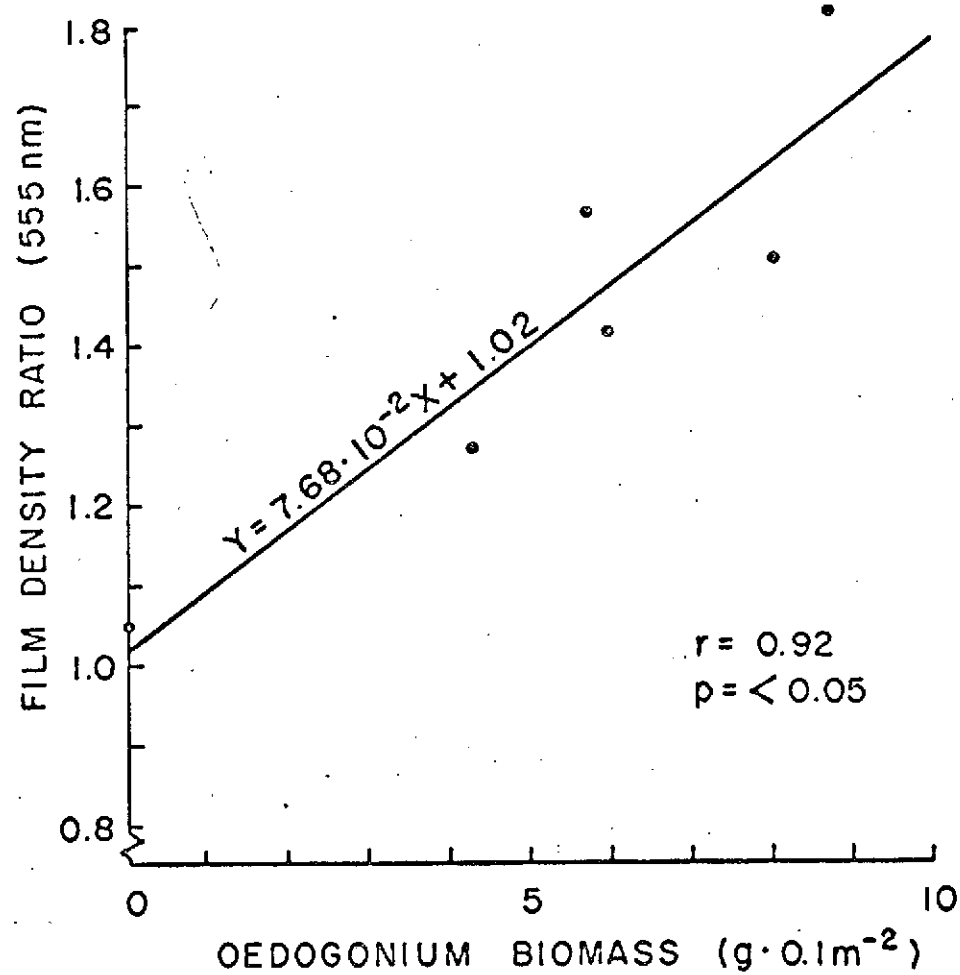


Figure 4: Regression analysis of Oedogonium harvest data and film densities.

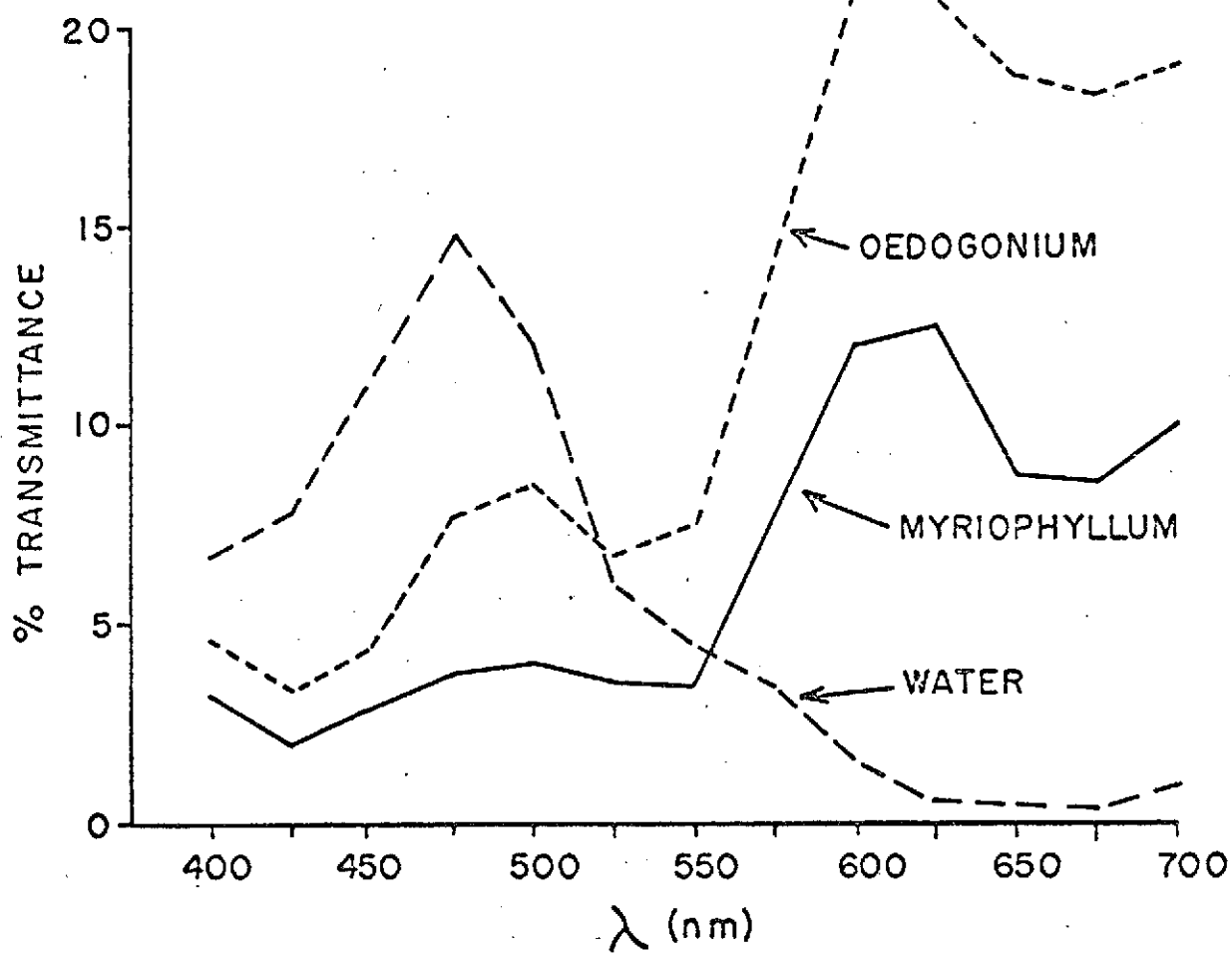


Figure 5: Spectral signatures on color infrared film of vegetation types that were investigated by photographic analysis.



## B. APPLICATIONS TO WATER RESOURCE PROBLEMS

### LAKE INVENTORY

The results obtained to date from the work on the remote sensing of macrophytes and of algae are being applied to the development of a lake classification system based on the extent of aquatic vegetation present for use by the Wisconsin Department of Natural Resources. Personnel from the DNR have indicated that a rapid and reliable method of determining the extent of aquatic vegetation present in a lake and the changes in the extent of aquatic vegetation from year to year would assist them in assessing the overall status of the lake for fisheries, recreation, and other purposes. In view of the fact that Wisconsin has in excess of 10,000 lakes, the advantages of remote sensing techniques appear rather obvious.

During the summer of 1973, consultations were held with DNR officials, and as a result, plans were made to photograph selected lakes in southern and eastern Wisconsin to serve as initial test sites for the development of a method. To date 10 lakes have been photographed using color IR film in the 35mm format. It is intended to apply densitometric methods in the analysis of the film to determine the types of vegetation present (macrophyte or algal), the biological nature of the vegetation present (e.g. green algae, blue-green algae, genus of macrophyte), and the extent to which each type is present in the lake. Maps of the lakes will then be drawn up. In addition, it is intended to devise a scheme of "heavy," "moderate," or "light" for describing the extent of cover in the lake and to employ these categories in setting up a classification scheme for use by the DNR. The precise definitions of heavy, moderate, and light must await analysis of the film and further discussion with DNR officials.

Once work on the initial test lakes has been completed, plans will be made for testing the scheme further during the summer of 1974 and for determining the practicality of the method in terms of cost, time, personnel, and other factors.

### INLAND LAKES RENEWAL

The Inland Lakes Renewal Project is investigating the effectiveness of various methods of lake rejuvenation, i.e. sand filling, plastic blankets, harvesting, chemical applications, etc. Of primary concern in the evaluation of the different methods under investigation is the effect of lake renewal treatment on excessive

or nuisance growth of aquatic plants. During the recent summer seven lakes that are receiving treatment or are due to be treated in the future were photographed. "Ground truth" investigations were conducted at each location to facilitate future analysis of imagery. Upon film analysis it is anticipated that the resultant data will be of considerable use to the state agencies that are planning the direction and evaluating the effectiveness of this program.

#### UNIVERSITY BAY

This is a joint effort of the Remote Sensing Program and the University Bay Project\* to evaluate the aquatic plant communities and ecological conditions in University Bay on the University of Wisconsin campus, Madison. The situation within the bay has been of concern since excessive plant growth and an increased siltation rate have combined to degrade the bay environment. Aerial photographs from this season will be used in the process of making management decisions. These photographs will also provide a "before" record that will be used in evaluating the impact of implemental management techniques.

\* Directed by the University Bay committee which is charged with the allocation of funds to be used for the protection, improvement, and restoration of the University Bay areas of the Madison campus.

### C. REMOTE SENSING OF ALGAL BLOOMS

#### Principal Investigator:

William Woelkerling, Assistant Professor, Department of Botany

#### RESULTS OF STUDIES PRIOR TO 1973

Laboratory investigations in an early phase of this study using two blue-green and two green algae indicated that remote sensing techniques have potential in obtaining qualitative and quantitative information on algal blooms in lakes and rivers. During the summer of 1972 field experiments were carried out to determine the extent to which qualitative information could be obtained under natural conditions. Two lakes in the Madison, Wisconsin area (Mendota and Monona) known to produce blooms of green and blue-green algae during the summer months were selected for study.

Each lake was monitored by a ground truth team for the occurrence of algal blooms; affected areas were then sampled simultaneously from the ground and from the air. Ground data on the type of organism and the environmental conditions was obtained and aerial data was obtained by means of color and color IR films in the 35 mm format. Both the living algae and the film were analyzed densitometrically. The resulting data has provided further evidence that it is possible to distinguish between blue-green and green algae by means of remote sensing techniques and that such distinctions can be made under field conditions as well as laboratory conditions. The results also indicate that it is possible to determine the extent to which the bloom covers the surface of the lake, and in the case of planktonic species, the extent to which the algal material is subject to movement as a result of wind.

#### STUDIES IN THE SUMMER OF 1973

Investigations were concentrated largely on Lake Mendota which experienced several intense blooms of both Cladophora (green algae) and Aphanizomenon (blue-green algae) as indicated on maps, Figures 6 and 7. The primary objective has been to gain insight into the use of remote sensing techniques for gathering quantitative information on algal blooms.

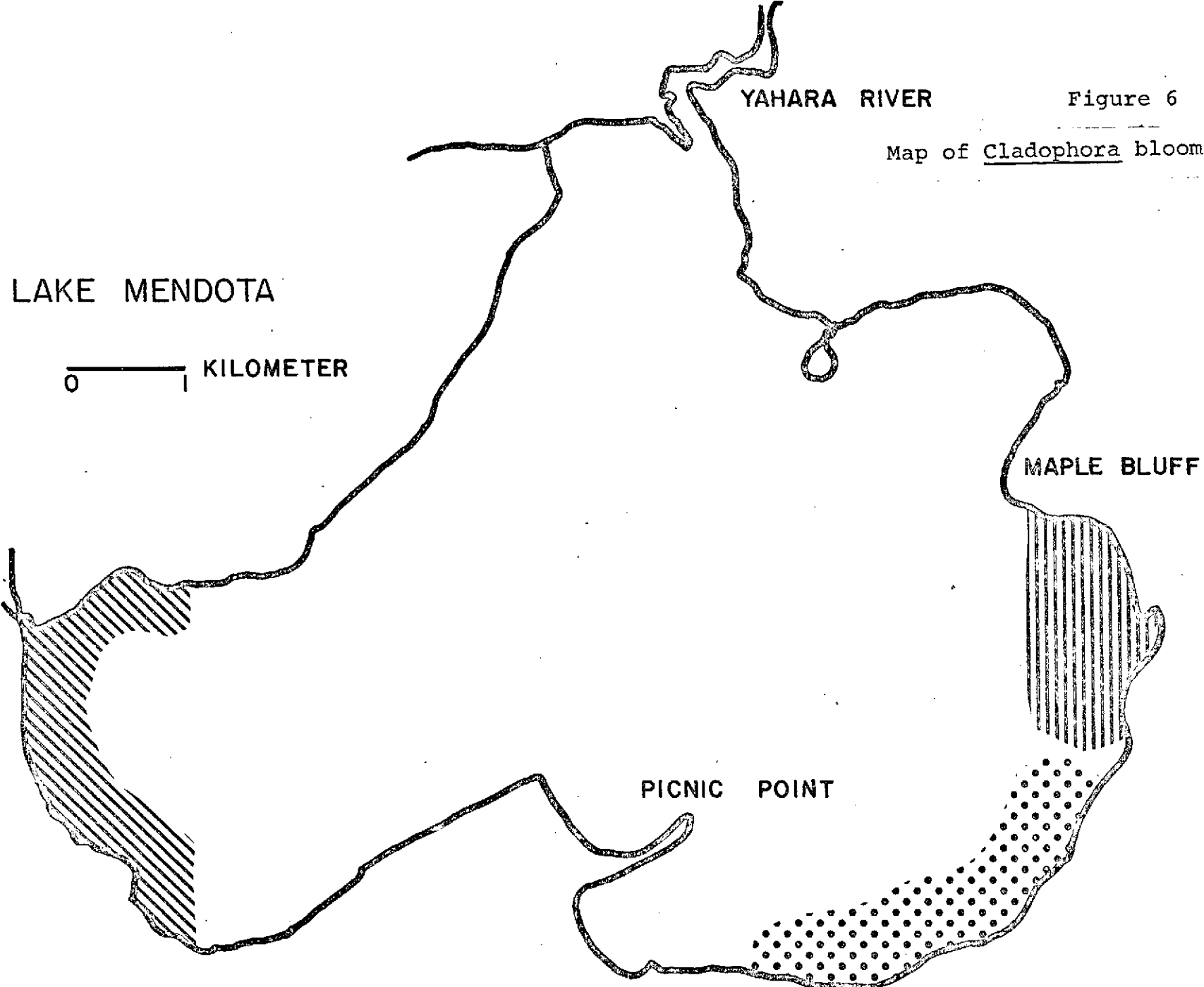
At the time of an air overpass, a 1.75 m diameter inflatable plastic ring was used to fence off a small portion of the bloom.

After photographing the bloom at full intensity, the concentration of algae within the ring was diluted first by half and then by a factor of 10 or more and successive aerial data was obtained. Ground truth included information on the type of organism present, taking secchi disc readings (to insure that no interference from bottom reflectance was present), and in one instance, the employment of the densitometer directly in the field to obtain data on the living plants. In addition, samples of the alga were brought back into the lab to obtain quantitative ground truth via population density counts and chlorophyll a levels analysis. In addition to color-IR film, black and white IR film with special filters covering the 600-650 and 650-700 nanometer ranges were used.

Results from this summer's work are in the process of being analyzed.

Figure 6

Map of Cladophora blooms, 1972-73.



CLADOPHORA BLOOM: JUNE 15-AUGUST 1, 1972 AND 1973



CLADOPHORA BLOOM: JULY 1 -AUGUST 1, 1973



CLADOPHORA BLOOM: JULY 15 -AUGUST 15, 1973

YAHARA RIVER

Figure 7

Map of Aphanizomenon blooms, 1972-73.

LAKE MENDOTA

0 — 1 KILOMETER

MAPLE BLUFF

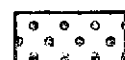
PICNIC POINT



APHANIZOMENON BLOOM: AUGUST 3, 1972



APHANIZOMENON BLOOM: JUNE 13-14, 1973



APHANIZOMENON BLOOM: JULY 16-19, 1973

## VII. LEGAL ASPECTS OF WATER POLLUTION CONTROL

### BY REMOTE SENSING

#### Principal Investigators:

Frank M. Tuerkheimer, Visiting Associate Professor of Law

James L. Clapp, Professor of Civil and Environmental Engineering & the Institute for Environmental Studies

The goal of this subproject was to establish remote sensing imagery as an effective legal implement through which administrative agencies and courts can not only investigate possible pollution sources but also legally prove the source of pollution.

To this end, aerial photography was acquired during the summer of 1973 of the Rock River from the confluence of the Yahara River south to Rockford, Illinois. A reconnaissance flight was also made along the Wisconsin River near Wausau, Wisconsin. Preliminary indications are that no test cases may be developed at sites on the Wisconsin River. Actual field experiments were postponed until the spring of 1974, because Dr. Tuerkheimer, the legal authority on the project, was called to Washington to serve with the Cox investigation. We intend to pursue the research topic upon the return of Dr. Tuerkheimer.

VIII. LIST OF PUBLICATIONS RESULTING FROM  
THE UNIVERSITY OF WISCONSIN REMOTE SENSING PROGRAM,  
1972-1973

A. NEW PUBLICATIONS

1. Scherz, James P., Development of a Practical Remote Sensing Water Quality Monitoring System, Proceedings, Eighth International Symposium on Remote Sensing of Environment, 2-6 October 1972.
2. McCarthy, Michael M., Monitoring Levels of Existing Environmental Impact Utilizing Remote Sensing Techniques, Proceedings, Eighth International Symposium on Remote Sensing of Environment, 2-6 October 1972.
3. Sacia, Niles F. and Bernard J. Niemann, Jr., An Annotated Bibliography-Research Theses: Lowery Creek Drainage Basin Study, University of Wisconsin, Remote Sensing Report Series, Number 20, October 1972.
4. Klooster, Steven A. and James P. Scherz, Water Quality Determination by Photographic Analysis, University of Wisconsin, Remote Sensing Report Series, Number 21, August 1973.
5. Villemonte, J.R., J.A. Hoopes, D.S. Wu and T.M. Lillesand, Remote Sensing in the Mixing Zone, University of Wisconsin, Remote Sensing Report Series, Number 22, August 1973.
6. Singh, Ramchandra S., A Cataloging System for Remote Sensing Data, University of Wisconsin, Remote Sensing Report Series, Number 23, August 1973.
7. Lillesand, Thomas M., The Use of Aerial Photography to Quantitatively Delineate Mixing Zones-A Progress Report, 2nd Annual Remote Sensing of Earth Resources Conference, Tullahoma, Tennessee, March 1973.
8. Gustafson, T.D. and M.S. Adams, Remote Sensing of Myriophyllum Spicatum L. in a Shallow, Eutropic Lake, Proceedings, Number 17, Remote Sensing and Water Resources Management, American Water Resources Association, 1973, In Press.
9. Clapp, J.L., R.W. Kiefer, M.M. McCarthy and B.J. Niemann, Jr., The Use of ERTS-1 Data for the Inventory of Critical Land Resources for Regional Land Use Planning, Proceedings, Eighth International Symposium on Remote Sensing of Environment, 2-6 October 1972.



## B. PREVIOUS PUBLICATIONS

10. Gramms, Lorne C., and William C. Boyle, A Literature Review of Remote Sensing for Water Quality, University of Wisconsin, Remote Sensing Report Series, Number 7, October 1971.
11. Kiefer, Ralph W., Effects of Date of Photography on Airphoto Interpretation Using Color and Color Infrared Films, University of Wisconsin, Remote Sensing Report Series, Number 9, Reprinted from the Proceedings of the 1970 International Symposium on Photography and Navigation, Columbus, Ohio, May 1970.
12. Kiefer, Ralph W., Sequential Aerial Photography and Imagery for Soil Studies, University of Wisconsin, Remote Sensing Report Series, Number 10, January 1972.
13. Adams, M.S., M. McCracken and K. Schmidt, Preliminary Results of Measurements of Primary Productivity of Aquatic Macrophytes and Periphyton in Lake Wingra During 1970-1971, University of Wisconsin, Memo Report #71-18, Eastern Deciduous Forest Biome, International Biological Program, October 1971.
14. Scarpace, F.L., and T. Green, The Use of a Thermal Scanner in the Remote Sensing of Water Pollution, University of Wisconsin, Remote Sensing Report Series, Number 11, April 1972.
15. Scherz, J.P., Final Report on Infrared Photography Applied Research Program, University of Wisconsin, Remote Sensing Report Series, Number 12, June 1972.
16. Rinehardt, G.L., and J.P. Scherz, A 35mm Aerial Photographic System, University of Wisconsin, Remote Sensing Report Series, Number 13, April 1972.
17. Yeske, L., T. Green, F. Scarpace and R. Terrell, Current Measurements in Lake Superior Using Aerial Photogrammetric Techniques: A Preliminary Report, University of Wisconsin, Remote Sensing Report Series, Number 14, April 1972.
18. Tuerkheimer, F.M., Legal Aspects of Water Pollution Detection Through Remote Sensing, University of Wisconsin, Remote Sensing Report Series, Number 15, April 1972.
19. Green, T., T. Mackenzie, S. Roffler, F. Scarpace, C. Sundby and T. Keating, The Point Beach Thermal Plume, University of Wisconsin, Remote Sensing Report Series, Number 16, April 1972.

20. Scarpace, F.L. and T. Green, On Rapid Changes and Periodic Temperature Structure in Thermal Plumes, University of Wisconsin, Remote Sensing Report Series, Number 17, June 1972.
21. Scarpace, F.L. and P.R. Wolf, Convenient Atmospheric Refraction Equations, University of Wisconsin, Remote Sensing Report Series, Number 18, August 1972.

IX. WORKING SEMINARS ON THE REMOTE SENSING  
OF THE ENVIRONMENT, 1972-1973

<u>DATE</u>	<u>TOPIC</u>	<u>SEMINAR LEADER</u>
22 Sept. 1972	"Stereoscopic Plotting Instruments"	Dr. Paul R. Wolf
29 Sept. 1972	"Monitoring Levels of Existing Environmental Impact Utilizing Remote Sensing Techniques"	Dr. Michael McCarthy
6 Oct. 1972	"Delineation of the Mixing Zone Using Color and Infrared Photography"	Mr. Thomas Lillesand
13 Oct. 1972	"Definition of the Kimberly Clark Mixing Zone"	Prof. J.A. Hoopes
20 Oct. 1972	"Introduction to Densitometric Methods and Equipment"	Mr. Thomas Lillesand Mr. Steven Klooster
27 Oct. 1972	"Interdisciplinary Research on the Application of ERTS-1 Data to the Regional Land Use Planning Process"	Dr. R.W. Kiefer Dr. B.J. Niemann Dr. Michael McCarthy
3 Nov. 1972	"Computer Programs for Data Analysis"	Dr. F.L. Scarpace Mr. Alan Voss
10 Nov. 1972	"Coastal Upwelling in Thermal Plumes"	Prof. T. Green
17 Nov. 1972	"Analytic Photogrammetry"	Mr. Steven Johnson
1 Dec. 1972	"Monitoring Productivity of Oedogonium in Lake Wingra"	Prof. Michael Adams Mr. Todd Gustafson
8 Dec. 1972	"All You Ever Wanted to Know About Thermal Scanners"	Mr. Robert Madding
19 Jan. 1973	"ERTS-B Proposal"	Dr. James L. Clapp
26 Jan. 1973	"Depth Penetration Studies"	Dr. James P. Scherz
9 Feb. 1973	"Portage Power Plant Project"	Dr. Daniel Willard
16 Feb. 1973	"Heavy Metals in the Environment"	Prof. Larry Haskins
23 Feb. 1973	"Air Pollution Monitoring"	Dr. Alden McLellan
2 March 1973	"Air Pollution Monitoring Study"	Prof. Verner Suomi

<u>DATE</u>	<u>TOPIC</u>	<u>SEMINAR LEADER</u>
9 March 1973	"Quantitative Analysis of a Thermal Plume"	Dr. F.L. Scarpase
16 March 1973	"Man-Computer Interactive Data Access System (McIDAS)"	Dr. Alden McLellan Dr. William Kuhlrow
23 March 1973	"Lake Superior Study"	Prof. T. Green Mr. Lanny Yeske
30 March 1973	"Macrophyte Monitoring"	Mr. Todd Gustafson
6 April 1973	"Hydrologically Active Source Areas"	Prof. Dale Huff
13 April 1973	"Algae Studies"	Prof. Wm. Woelkerling
27 April 1973	"Earth Resources Technology Satellite (ERTS)"	Dr. R.W. Kiefer
4 May 1973	"Quantitative Delineation of the Mixing Zone"	Mr. Thomas Lillesand